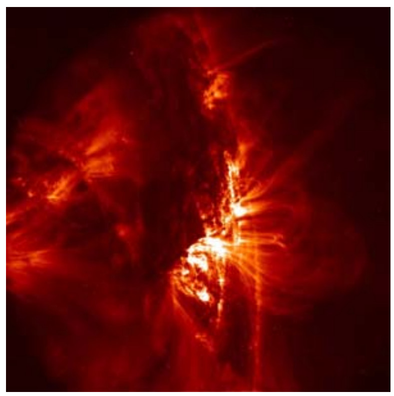
2003 Space Science Enterprise Strategy



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1. Introduction

NASA's Space Science Enterprise has achieved remarkable results in our mission to explore the Universe and inspire the next generation. In the three years since the last Space Science Strategic Plan, we have:

[Insert images:

Looked below the Sun's surface,

Traced the flow of energy from solar eruptions to the Earth's atmosphere,

Discovered abundant water ice on Mars,

Found evidence of sedimentary processes on Mars,

Detected and atmosphere on a planet outside our Solar System,

Made the first detailed full-sky map of the oldest light in the Universe,

Discovered dark energy that is accelerating the expansion of the Universe,

Discovered that supermassive black holes pervade the Universe, and

Tripled the scope of NASA's space science education and outreach program.]

The pace of extraordinary discoveries will quicken in the years to come, as new technologies allow us to explore with unprecedented clarity profound mysteries of life, space, time and the workings of the Universe. Our programs for the next five years build upon these discoveries in the pursuit of answers to fundamental questions. We will search for signs of life elsewhere, as we strive to understand all that the term “life” may encompass. We will look for the origins of our Universe, including its beginning, its structure, and the formation of our cosmic neighborhood of planets, stars, and galaxies. We will learn about our nearest star, the Sun, to understand its effects on our lives and on the evolution of the Solar System. And we will invest in the research and technology needed to achieve these Objectives.

Conveying scientific results to the public is as important as the scientific discoveries themselves. Every program in Space Science Enterprise will continue its commitment to education and public outreach. We will use the unique features of our science to contribute exciting new material to national science curricula and to inspire both the young and old, but particularly the next generation, who represent humanity's future.

This five-year Strategy communicates our Objectives and our methods to achieve them. All of our flight programs, research programs, education and public outreach efforts, and collaborations are defined by and measured against the Objectives laid out in here and in the NASA 2003 Strategic Plan. In short, this is a guide to what we intend to do and why.

The following sections show the traceability of the Enterprise’s Objectives from the overarching NASA Vision, Mission, and Strategic Goals. These describe the processes we use to achieve the Objectives and elaborate on our Science Themes and program elements. The unique content of and tools for our education efforts are also described, as are the technology requirements and development processes. Finally, we conclude with discussions of critical partnerships and of our unique resource requirements, including human, capital, and information resources.

2. NASA Vision and Mission

NASA is embarking on an ambitious adventure of exploration and inspiration. The NASA Vision communicates simply, but powerfully, our mandate in the 21st century. Our Vision is to:

Improve life here,

Extend life to there, and

Find life beyond.

The NASA Mission lays out a clear path to the future. We are called to:

Understand and protect our home planet,

Explore the Universe and search for life, and

Inspire the next generation of explorers…as only NASA can.

This Mission provides a framework for developing goals each part of NASA must achieve. As provided in the Agency Strategic Plan, NASA has seven Strategic Goals, which enable us to focus planning, manage programs, and measure results. Each of the Agency's six Enterprises—Space Science, Earth Science, Biological and Physical Research, Aerospace Technology, Education, and Space Flight—uses the Strategic Goals to define its programs.

Mission Area	Goal	NASA Enterprise
Understand and protect our home planet.	1. Understand the Earth system and apply Earth system science to improve prediction of climate, weather, and natural hazards.	Earth Science, **Space Science**, Space Flight
	2. Enable a safer, more secure, efficient, and environmentally friendly air transportation system.	Aerospace Technology
	3. Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.	Biological and Physical Research, Space Flight, Aerospace Technology, Earth Science
Explore the Universe and search for life.	4. Explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space.	Biological and Physical Research, Space Flight
	5. Explore the Solar System and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.	**Space Science**, Space Flight
Inspire the next generation of explorers.	6. Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics. 7. Engage the public in shaping and sharing the experience of exploration and discovery.	**Space Science**, Earth Science, Biological and Physical Research, Aerospace Technology, Education, and Space Flight

Among these Goals, the Space Science Enterprise is entrusted with primary responsibility for Goal 5: "To explore the Solar System and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere." We also support the first Goal, and the education and public outreach Goals (6 and 7).

3. Role of the Space Science Enterprise

The Space Science Enterprise carries out for NASA, and on behalf of the science community, the highest priority space science research and investigations. The Enterprise is at the heart of exploration and discovery. Through a portfolio of programs and projects, the Enterprise provides opportunities for research, data analysis, and development of new flight missions.

At the Agency level, NASA's Goals are very broadly stated. To enable the Space Science Enterprise to plan, manage, and measure progress, the Agency Goals are further broken down into Space Science Objectives.

Scientists at universities and U.S. institutions outside of NASA guide the formulation and articulation of the Enterprise Objectives. The National Research Council, for example, performs independent studies of the status of scientific knowledge in key areas and provides recommendations for future investigations. Based in part on the NRC inputs, the Enterprise's Space Science Advisory Committee and its discipline subcommittees identify high-priority science objectives and suggest a program of flight missions to address the objectives.

The Enterprise integrates these scientific and engineering inputs—considering also such factors as technology readiness and resource projections—and formulates an integrated program of flight missions, technology development and scientific research. The consolidated Enterprise Objectives document a consensus on priorities. They are used as a reference for selection of investigations and other programmatic decision making, as input to the NASA Strategic Plan and Government Performance and Results Act (GPRA) assessments and as tools for program and budget advocacy. In the way, we begin to move from concept to discovery.

The programs and tasks implemented to meet Enterprise Objectives are funded through one of five Space Science Themes, namely Solar System Exploration, Mars Exploration, Sun-Earth Connection, Astronomical Search for Origins, and Structure and Evolution of the Universe. These Themes provide the structure for budget planning, management, and performance reporting. Every program implemented to meet the Enterprise Objectives is managed and budgeted within these Space Science Themes. For the purpose of managing program activities, the Enterprise further divides the Strategic Science Objectives into Research Focus Areas. These areas are summarized within the Theme Program discussions, and the full structure is provided in the **appendix**.

Education and public outreach are so important to NASA's overall Mission that a separate set of Strategic Goals has been established for them. Every Space Science Enterprise program contributes actively and directly to Enterprise Objectives that support the Agency's education Goals. Management and funding of these activities are distributed throughout the Themes.

Agency Strategic Goal	Space Science Enterprise Objective	Space Science Theme
1. Understand the Earth system and apply Earth system science to improve prediction of climate, weather, and natural hazards.	Understand the origins and societal impacts of variability in the Sun-Earth connection	Sun-Earth Connection
	Catalog and understand potential hazards to Earth from space.	Solar System Exploration
5. Explore the Solar System and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.	Learn how the Solar System originated and evolved to its current diverse state.	Solar System Exploration
	Determine the characteristics of the Solar System that led to the origin of life.	
	Understand how life begins and evolves.	
	Understand the current state and evolution of the atmosphere, surface, and interior of Mars.	Mars Exploration
	Determine if life exists or has ever existed on Mars.	
	Develop an understanding of Mars in support of possible future human exploration.	
	Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.	Sun-Earth Connection
	Understand the fundamental physical processes of space plasma systems.	
	Understand how today's Universe of galaxies, stars, and planets came to be.	Astronomical Search for Origins
	Learn how stars and planetary systems form and evolve.	
	Understand the diversity of other worlds and search for those that might harbor life.	
	Discover what powered the Big Bang and the nature of the mysterious dark energy that is pulling the Universe apart.	Structure and Evolution of the Universe
	Learn what happens to space, time, and matter at the edge of a black hole.	
	Understand the development of structure and the cycles of matter and energy in the evolving Universe.	
6. Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.	Improve student proficiency in science, technology, engineering and mathematics by creating a culture of achievement, using educational programs, products, and services based on NASA's unique missions, discoveries, and innovations.	All Themes
	Motivate K-16+ students from diverse communities to pursue science and math courses and, ultimately, college degrees in science, technology, engineering, and mathematics.	

	Enhance science, technology, engineering, and mathematics instruction with unique teaching tools and experiences that only NASA can provide, that are compelling to educators and students.	
	Improve higher education capacity to provide for NASA's and the nation's future science and technology workforce requirements.	
7. Engage the public in shaping and sharing the experience of exploration and discovery.	Improve the capacity of science centers, museums, and other institutions through the development of partnerships, to translate and deliver engaging NASA content.	All Themes
	Engage the public in NASA missions and discoveries through avenues in public programs, community outreach, mass media, and the Internet.	

4. Achieving Space Science Objectives

The Space Science Enterprise achieves its Objectives through flight missions and ground-based scientific research and data analysis. The interplay and iteration between flight missions and supporting research is the source of vitality for the whole program.

All Space Science activities are funded through and managed within the Themes using standard processes designed to conduct business fairly and consistently across the Enterprise. This section describes the processes and programs that enable us to achieve our Objectives.

4.1 Program Elements

Space science investigations are very diverse, from the winds on Venus to the winds generated by supermassive black holes at the edge of the visible Universe, but the Enterprise applies standard processes to conduct them. For example, the Enterprise applies a uniform approach to selecting and implementing the individual flight projects in every Theme program. Supporting research and analysis cover an enormous breadth of topics, as do technology development and demonstration activities, but they too are managed to the extent possible in a consistent way. Education and public outreach, which are important mandates for the space science program, seek efficiencies by adopting common strategies and organizational approaches across the Enterprise.

4.1.1 Flight Missions

The Space Act of 1958 established NASA as a mission agency that sponsors and conducts flight missions to obtain data in furtherance of its objectives. This proved to be the "Right Stuff" during the lunar missions of the 1960s and 1970s, and this legacy of inspiration today continues with triumphs such as the Hubble Space Telescope. In the Space Science Enterprise, flight missions range from suborbital projects—including balloons, sounding rockets, and airplanes—to interplanetary probes and flagship observatories. In executing its flight missions and obtaining these data, the Enterprise uses a consistent approach to selecting and executing flight missions.

First, all investigations and missions selected and flown must respond to Agency Goals and Enterprise Objectives. In some cases, the Enterprise specifies mission science objectives and requirements based on the strategic planning process. Instrument investigations to meet these requirements are then solicited from the scientific community. In other cases, often called “community-based” missions, Principal Investigators from the scientific community form teams to propose entire missions, from basic science requirements through mission operations and science data analysis after launch. These teams often include universities, industry, outside laboratories, and NASA Centers.

Space Science Enterprise programs are firmly anchored in the Agency Strategic Goals and Enterprise Objectives. We combine consecutive missions that address a cluster of science objectives into “mission lines.” These mission lines enable us to fly successive missions as science priorities dictate and as resources and technology permit. Among the mission lines are the Discovery Program, which comprises Solar System Exploration and Origins missions; Mars Scout, which includes regular opportunities for innovative research in support of Mars Objectives; New Frontiers, a new line for planetary exploration; Solar Terrestrial Probes; the Living With a Star (LWS) line; and the Explorer Program (see inset). These are some of the most successful programs within NASA and are the model for future missions.

The Enterprise encourages broad participation in all of its flight missions among outside industry and the academic community. Foreign partners are also invited to participate on a no-exchange-of-funds basis. A fundamental premise of the Enterprise's approach to implementing all aspects of its program is open and competitive merit selection. That is, opportunities are open to all proposers, within fixed rules, via public announcement, and selections are based primarily on scientific and technical merit as evaluated by independent peer review. Another premise is that instrument development and mission implementation are managed to fixed performance requirements and cost caps. Finally, extension of a mission's operation beyond its funded baseline is determined on the basis of a competitive selection based on past and prospective scientific productivity of the mission compared to other ongoing missions.

> **Explorers**
>
> **NASA's Explorer Program** is an example of the mission lines that are vital to realizing the Enterprise's science objectives. Explorers are space physics and astronomy missions intended to study the Sun, to examine the space environment of the Earth and other planets, and to observe the Universe beyond the Solar System.
>
> Explorer offers frequent opportunities to carry out community-based small- and medium-sized missions (SMEX and MIDEX) that can be developed and launched in a short (approximately four-year) time frame. These focused missions can address science of great importance, which complements the science of strategic missions. They allow quick response to new scientific and technical developments. The Mission of Opportunity option enables valuable collaborations with other agencies, both national and international. Explorer missions and Missions of Opportunity are selected for science value through competitive peer review.
>
> Each Explorer solicitation elicits more high-quality experiments than can be implemented. Peer review, the ability to implement new, creative ideas, and quick reaction to recent discoveries are essential elements of the high science value of all space science mission lines.

4.1.2 Scientific Research and Analysis

Each science Theme sponsors research programs that provide opportunities to develop new ideas, concepts, and methods, and to analyze and interpret data from space science missions. Research programs are crucial to the space science community, because ideas developed here often form the basis for new mission concepts. Strong university involvement in the programs provides the additional benefit of training graduate students and the builders of future space missions; veterans of the programs often become principal investigators of flight missions and major instrument builders.

The Space Science Enterprise research and analysis programs encompass four key program elements that lead to the development and test of new space science concepts and support the scientific analysis of the data resulting from space science missions. These are Research and Analysis, Data Analysis, Suborbital Programs, and Science Data and Computing Technology.

Research program participants are selected through a broadly advertised, open, competitive process. Proposals are solicited, usually annually, through NASA Research Announcements developed by the discipline scientist responsible for the particular program element.

<u>Research and Analysis</u> (R&A) provides the foundation of the space science program and support for the formulation of new scientific questions and strategies.

The Space Science R&A program supports research tasks across the entire breadth of the space sciences, including all aspects of cosmology, stellar and galactic astronomy and astrophysics, astrobiology and cosmochemistry, the origins and evolution of planetary systems, the atmospheres, geology, and chemistry of the Solar System's planets (other than the Earth), solar physics, heliospheric physics (including interplanetary space, comets, and asteroids), and the physics of the ionospheres, thermospheres, and magnetospheres of the Earth and planets. Such tasks incorporate the full range of scientific techniques, including development of new detectors and instruments, corroborative ground-based observations, laboratory measurements, suborbital rocket and balloon payload experiments, supporting technologies, modeling, basic theory, and the analysis of archival space data, especially those from NASA missions. In all cases, a prime factor for support of these tasks is the relevance that they have to Space Science Objectives, as well as past, current, and/or future NASA missions and programs.

Advanced detector and instrument system concepts are developed under sponsorship from space science R&A programs. For example, detector concepts for the Hubble Space Telescope, the Chandra X-ray Observatory, the Solar and Heliospheric Observatory (SOHO), and the Space Infrared Telescope Facility (SIRTF) were developed largely within the R&A program. Likewise, future generations of instruments slated for possible use on Explorer, Discovery, and other strategic missions are developed within the R&A program, which includes dedicated programs for instrument development.

Ground-based programs are particularly valuable in preparing for new missions, testing new technologies, investigating new observing strategies, and providing data to test new analysis techniques or for correlation with complementary space-based measurements.

Laboratory measurements can provide the essential link between observations and scientific conclusions. R&A programs, for example, support laboratory and theoretical studies of atomic and molecular properties and plasma physics that are central to our understanding of important aspects of Solar System plasmas.

Similarly, the Laboratory Astrophysics program impacts a tremendous breadth of topics, from the coldest regions deep in molecular clouds to the extraordinary environments around supermassive black holes. Laboratory data on atomic and molecular properties are needed to interpret astrophysical spectra. Under R&A, techniques are being developed for curating and analyzing returned samples of cometary dust and eventually of Mars's surface. Maintenance and improvement of existing facilities are essential components of this effort.

Supporting technologies, such as lightweight mirrors, optical coatings, gratings, and solar blind filters, are developed through R&A programs to the level of laboratory-demonstration models. The advance of measurement capabilities influences our priorities for starting and launching future space missions. Thus, this R&A component has a direct influence on future mission planning.

The **modeling and theory work** in the R&A program enable research directions, predicts observable phenomena, and enables the analysis and interpretation of data returned by NASA's space science missions so as to exploit them fully and achieve strategic objectives. Prediction of observable and measurable phenomena drives future missions, spacecraft, and payload design requirements.

R&A programs can be broad in their reach in affecting different science objectives and themes. As pointed out in the NRC report *Life in the Universe*, **Astrobiology** (see box) may represent the extreme in supporting multiple Themes with linkages to Solar System Exploration, Astronomical Search for Origins, and the Mars Exploration Program.

Astrobiology

Life on Earth exists under extreme conditions, in the heat and acidity of volcanoes and in the cold darkness of the deepest seabed. Could life exist in the icy oceans of Jupiter's moons or in the atmosphere of an extra-solar planet? This question captures the essence of the exciting and emerging discipline of astrobiology.

The **Astrobiology** R&A programs have been at the forefront of an effort to break down discipline barriers to promote vigorous research at the boundaries between traditional scientific disciplines. Astrobiology spans a wide range of investigations, including understanding the nature and distribution of habitable environments in the Universe; exploring for past or present habitable environments, prebiotic chemistry, and signs of life elsewhere in our Solar System; understanding how life emerges from cosmic and planetary precursors; understanding how past life on Earth interacted with its changing planetary and Solar System environment; understanding the evolutionary mechanisms and environmental limits of life; understanding the principles that will shape the future of life, both on Earth and beyond; and determining how to recognize signatures of life on other worlds and on early Earth.

Astrobiology is multidisciplinary in its content and interdisciplinary in its execution. Four openly competed, complementary R &A programs provide the mechanism and intellectual foundation to prepare for and guide future space exploration opportunities.

- The exobiology/evolutionary biology program focuses individual investigator research on the origins and evolution of life, using the Earth as a benchmark against which the potential for life in the galaxy is to be measured.
- The NASA Astrobiology Institute, an institute-without-walls, enables concentrated science collaboration by expert teams located across the US and world to answer fundamental questions in astrobiology.
- An instrument development program encourages concept to laboratory bench-level development of astrobiology-specific instruments capable of operating in space and extraterrestrial environments.
- A program of science-driven robotic explorations of extreme environments expands our understanding of life on Earth and improves our capacity for semi-autonomous operations when exploring other planetary bodies.

As part of its fundamental principles, Astrobiology encourages planetary stewardship through an emphasis on protection against forward and back biological contamination and recognition of ethical issues associated with exploration. In addition, Astrobiology appreciates that a broad societal interest in its endeavors offers a crucial opportunity to educate and inspire the next generation of scientists, technologists and informed

<u>Data Analysis (DA)</u> supports the analysis of scientific data returned by space science missions, turning obtuse binary code into beautiful images of the Orion nebula, a looping solar flare, or the crinkled surface of Mars. The goal of the DA and Guest Investigator (GI) programs is to maximize the scientific return from NASA's investment in spacecraft and other data collection sources. The DA program is fundamental to achieving Space Science Objectives because it funds data analysis during and after a spacecraft's life span. Funding also supports long-term data archiving and database services. Data Analysis is called out in a number of NRC reports and science discipline surveys as critical to the Enterprise.

Data Analysis supports interpretive research of mission data that leads to discoveries and predicts new directions for future scientific investigations. Work in this program is performed by mission instrument teams and interdisciplinary scientists competitively selected to participate on an individual mission for its lifetime. Support for investigations beyond a mission's baseline operation is determined through a competitive senior review process. In addition, there are periodic open and competitive solicitations for guest investigators to analyze data from these missions.

<u>Suborbital Research Carriers</u>, high-altitude balloons and sounding rockets, catapult us to the brink of space and are used for scientific research and to develop flight experiments. Riccardo Giacconi's experiment aboard an Aerobee rocket cracked the Earth's atmosphere for a mere 350 seconds on June 18, 1962. This event marked birth to the field of X-ray astronomy, the first of many accomplishments that lead to Giacconi's 2002 Nobel Prize in Physics.

The goal of NASA's suborbital balloon and sounding rocket operations is to provide low cost, frequent access to space. Here, diverse scientific problems can be addressed in a wide range of scientific disciplines; new technology and techniques can be flight-tested relatively inexpensively; and students can be trained on time scales commensurate with their graduate studies. Detectors and instruments developed in the R&A programs are frequently tested under real-life conditions in the sounding rocket and balloon programs before they are selected to fly on much more expensive spacecraft.

Sounding rocket and balloon investigations are especially suited to the university research environment. They are characterized by diversity in the number and types of scientific investigations. In a single year, typically over 200 scientists from more than 60 different institutions are involved in balloon and sounding rocket missions. These suborbital missions are a primary source of new experimental scientists, so they help form the foundation of the NASA space science orbital missions.

The payloads are funded through the R&A program, independently of the flight operations. In addition, the Explorer Program allows long-duration balloon missions to be proposed as "Missions of Opportunity". Although NASA provides reliability and quality assurance oversight, the Principal Investigator (PI) is completely responsible for the mission's success.

Balloon flight operations provide a cost-effective way to make scientific observations in the near-space environment, where the atmospheric pressure is a small fraction of that at sea level. Balloons frequently offer the only viable flight opportunity for large or heavy instruments, or cost-constrained experiments. Balloons are launched from Pole to Pole and on the flatlands in between. They provide the primary flight-test and calibration opportunities for space-based astronomy and physics missions.

Sounding rocket operations are uniquely suited to studying variations in the terrestrial atmosphere at a range of altitudes. They are also used to study the Earth's magnetosphere and near space environment; incoming energetic particles and solar radiation, including the production of the aurora and the coupling of energy into the atmosphere; and radiation from the Sun, stars, and other celestial objects. Like balloons, sounding rockets are used to flight-test and calibrate instruments and experiments being developed for future orbital missions.

The NASA Wallops Flight Facility manages both the sounding rocket and balloon programs.

<u>Science Data and Computing Technology</u> provides Enterprise-wide, multidisciplinary support in the areas of science data management, scientific computing and communications, and applied information systems research and technology. Vast amounts of data are returned from space science missions. Without an adequate storage and retrieval mechanism, this precious data, the fruit of years of labor, would be wasted. The Space Science Enterprise has a strong tradition of user-driven data systems that include systematic processing and archiving of data, which is ultimately placed in open archives for both scientists and amateur astronomers alike to access. The future Enterprise science data and information systems environment will continue to exploit advances in information technology to evolve an interoperable framework of data archives providing expedient access to widely distributed datasets, along with the ability to integrate data from multiple missions into a larger context.

The "virtual observatory" is a bold endeavor that represents the intersection of these advances in information technology. This allows for exploration and data mining of the multitude of astronomical data from disparate observatories -- from ground-based radio telescopes to space-based X-ray and gamma-ray platforms, the entire Universe in all its electromagnetic glory at one's fingertips. Theoretical modeling and numerical simulations, as well as assimilation of observational data into the models, will be enabled within the “virtual observatory” environment. Examples of virtual observatory collaborations include the Virtual Solar Observatory and the National Virtual Observatory (NVO) initiative to integrate most of the nation’s astronomical data.

The design and implementation of these virtual observatories will follow the proven formula of the Space Science Enterprise: they will be driven by the requirements of future missions and the needs of the user communities in realization of the Enterprise’s science Objectives. This framework will build upon the current, successful discipline-specific science capabilities, including the Planetary Data System, the astrophysics wavelength-oriented science archive research centers, the Solar Data Analysis Center, and the multi-discipline National Space Science Data Center (NSSDC). Opportunities to coordinate with related activities in other federal agencies and international partners will be encouraged.

Science Data Management supports the Enterprise-wide policies and standards to enhance interoperability, compatibility, and sharing across discipline science efforts. This promotes a more coherent and coordinated Space Science Enterprise-wide data environment to improve quality, accessibility, and usability of NASA's space data for scientists, educators, and the general public. This program element sponsors the multi-discipline NSSDC as part of the overall federation of Space Science Enterprise data capabilities mentioned above.

Scientific Computing and Communications supports application of high-performance computing and communications technologies to meet space science needs. The marriage of advancing detector technology and high performance computational capability will continue to produce critical breakthroughs in our understanding of the cosmos. Current efforts in large-scale computation include designing "numerical laboratories" to model physical processes and effects not possible to study in the laboratory, such as the behavior a matter around a black hole. We will continue to pursue closure between theory, simulations, and observations to expand our understanding and, ultimately, predictive capabilities. Examples of the more computationally intensive endeavors include the Living With a Star program aimed at scientific breakthroughs that will allow solution of space-weather problems, gravitational wave source modeling, and other numerical relativistic astrophysics simulations.

Applied Information Systems Research and Technology uses new developments in computer science and information technology to enrich space science missions and research programs. Advanced software tools, algorithms, and computational methods are selected through open, peer-reviewed solicitations and promote strong collaborations with the space science community, the computer science community, data systems engineers and technologists, and academic and private sector technology innovators.

Tools and capabilities developed under the program are broadly disseminated through the space science data and computing infrastructure and/or infused directly in missions.

4.1.3 Education and Public Outreach

Employees at NASA know that the mere mention of their jobs to friends, relatives and acquaintances evolves into a multitude of questions about life on Mars or the fate of matter around a black hole. Astronomy has the capacity to captivate the public unlike any other scientific discipline. By engaging the imaginations of teachers, students, and the general public, space science has demonstrated extraordinary potential for strengthening interest in science and improving the quality of science, technology, engineering, and mathematics education in America. By attracting bright individuals to advanced study in technical fields, space science also plays a significant role in ensuring a continuing cadre of trained scientists, technologists, and engineers to meet our society's needs in the 21st century.

The Space Science Enterprise has developed an extensive education and public outreach program that strongly supports the NASA mission to "inspire the next generation of explorers." Consistent with NASA priorities, the two main elements of our education and public outreach program are to "inspire and motivate students to pursue careers in science, technology, engineering, and mathematics" by supporting education in the nation's schools, and to "engage the public in shaping and sharing the experience of exploration and discovery" by supporting informal education and public outreach efforts. Our program emphasizes sharing the results of our missions and research programs with wide audiences and using space science discoveries as vehicles to improve teaching and learning at all levels. Our commitment to education places a special emphasis on pre-college education, diversity, and increasing the general public's understanding and appreciation of science, technology, engineering, and mathematics. This emphasis complements our traditional role in higher education, where we will continue to support professional education through research involvement as a central element of meeting our responsibility to help create the scientific and engineering workforce of the future.

<u>Education and Public Outreach (E/PO) Implementation Approach</u>

There is a set of fundamental principles we use in planning and evaluating space science E/PO activities. We ensure that a substantial, funded education and outreach program is incorporated into every space science flight mission and research program. This practice directly involves the space science community in enhancing education at the precollege level and fostering a broad public understanding of science. Because of our commitment to contribute as only NASA can, we establish strong and lasting partnerships between the space science and education communities. We also maintain a national network to identify high-leverage education and outreach opportunities. To increase availability of our material, we provide easy access to education and outreach products at scientific and educational events, such as conferences, and via the Internet. We also provide opportunities for participation in the space science program to an increasingly diverse population, including opportunities for minorities and minority universities, which compete for and participate in space science missions, research, and education programs. Finally, we evaluate the quality and impact of all space science education and outreach programs.

The Space Science Enterprise approach to supporting NASA's education and public outreach goals and objectives is based on our policy of incorporating education and public outreach as an integral component of all of our activities, both flight missions and research programs. Contributing to education and outreach is the collective responsibility of all levels of Enterprise management and of all participants in the space science program. Space science mission personnel and researchers, in particular, are encouraged to become active participants in education and outreach activities. We focus on identifying and meeting the needs of educators and on emphasizing the unique contribution NASA space science can make to education and the public understanding of science.

With limited resources, leverage is key to building a national program that contributes both to improving teaching and learning at the pre-college level and to increasing the scientific literacy of the general public. The Enterprise achieves this leverage in pre-college education by building on existing programs, institutions, and infrastructure and by coordinating activities and encouraging partnerships with other ongoing education efforts. We have also established alliances for informal education with science centers, museums, and planetariums, as well as with producers of public radio and television programs, and we are experimenting with new ways to bring the results of the space science program to teachers, students, and the public through partnerships with community organizations of many different types across the country. In all of these partnerships, we seek to provide space science content and expertise while relying on our partners to provide the educational expertise and context.

To improve the effectiveness of our education and public outreach program, we operate a national space science support network that seeks out, develops, and sustains high-leverage partnerships; helps the space science community become involved in education and outreach; and ensures that products and programs developed locally become national resources. We make our educational products readily available to educators through an online education resource directory that is linked to other NASA and national databases of educational materials. We provide opportunities for participation in space science programs by an increasingly diverse population through emphasizing inclusiveness in all of our education and public outreach efforts and by developing special opportunities for minority students and educators, minority institutions, students with disabilities, and other targeted groups to participate in the space science program. The Braille book of Hubble images entitled "Touch the Universe," for example, offered to the visually-impaired community for the first time access to these wonderful pictures many of us take for granted. Finally, we seek expert feedback on quality and impact through a variety of means including peer review, evaluation by an external evaluation group, and through other focused efforts directed towards providing third-party advice on the quality and overall direction of the program.

Since the previous Enterprise Strategic Plan was released in 2000, our education and public outreach efforts have reached a very visible level of maturity. Funded education and public outreach programs are embedded in all of our missions and research programs; partnerships have been established with hundreds of local, regional, and national institutions and organizations; and thousands of education and public outreach events are taking place annually throughout the Nation.

Future Efforts

Our future education and public outreach efforts will build on these activities and accomplishments with an emphasis on improving their quality and impact, and on extending their reach into new areas. For example, we will:

- Continue to contribute to the professional training of scientists by supporting research assistantships and post-doctoral opportunities offered through OSS research awards and through other NASA research and higher education programs.
- Coordinate our education and public outreach program with other similar efforts undertaken throughout NASA in order to optimize our contribution to the Agency's overall education program.
- Provide opportunities for students to work directly with NASA space science missions, facilities, and data. Such opportunities are particularly important for precollege students, where the experience of being involved in a NASA mission or research program inspire career choices and life-long interests.
- Increase our efforts to provide opportunities for diverse populations to participate in space science missions, research, and education and outreach programs. We will continue and expand our efforts to develop space science capabilities at minority institutions, and we will develop and enhance partnerships with special interest organizations such as professional societies of minority scientists to provide new avenues for reaching and involving diverse populations. We will develop working partnerships and coordinate with the diversity initiatives of scientific professional societies, and we will extend the accessibility of space science E/PO programs and products to an increasingly broad population, including such groups as girls, residents of rural areas, and persons with disabilities.
- Improve the coherence of NASA space science materials for educators by building a framework that will show the appropriate standards-aligned sequencing of space science topics throughout the K-12 years and provide overall direction and context for the materials being produced by individual missions.
- Build on strong mutual interests between the Space Science Enterprise and the science center, museum, and planetarium communities by continuing to provide space science content, materials, and technical expertise to support the development of exhibitions and programs.

- Enrich the science, mathematics, engineering, and technology educational efforts of community groups such as the Girl Scouts, 4H Clubs, and Boys and Girls Clubs through the introduction of space science.
- Take advantage of the advanced-technology nature of much of the Space Science Enterprise's program to develop new materials and new programs in technology education
- Provide coherent and sustained professional development to personnel engaged in NASA space science education and public outreach in order to increase the effectiveness of their work in education.
- Extend and deepen previous work on educational evaluation to more fully understand the impact of the Space Science E/PO effort, and continue to use the results of assessment and evaluation studies to improve the quality of Space Science E/PO programs.
- Seek out and capitalize on special events and particularly promising opportunities in our scientific program to bring space science to and involve the public in the process of scientific discovery and to use space science to improve science, engineering, mathematics, and technology education at all levels. Such opportunities arise naturally from within our missions and science programs, and they are discussed in the context of each research theme in the sections that follow.

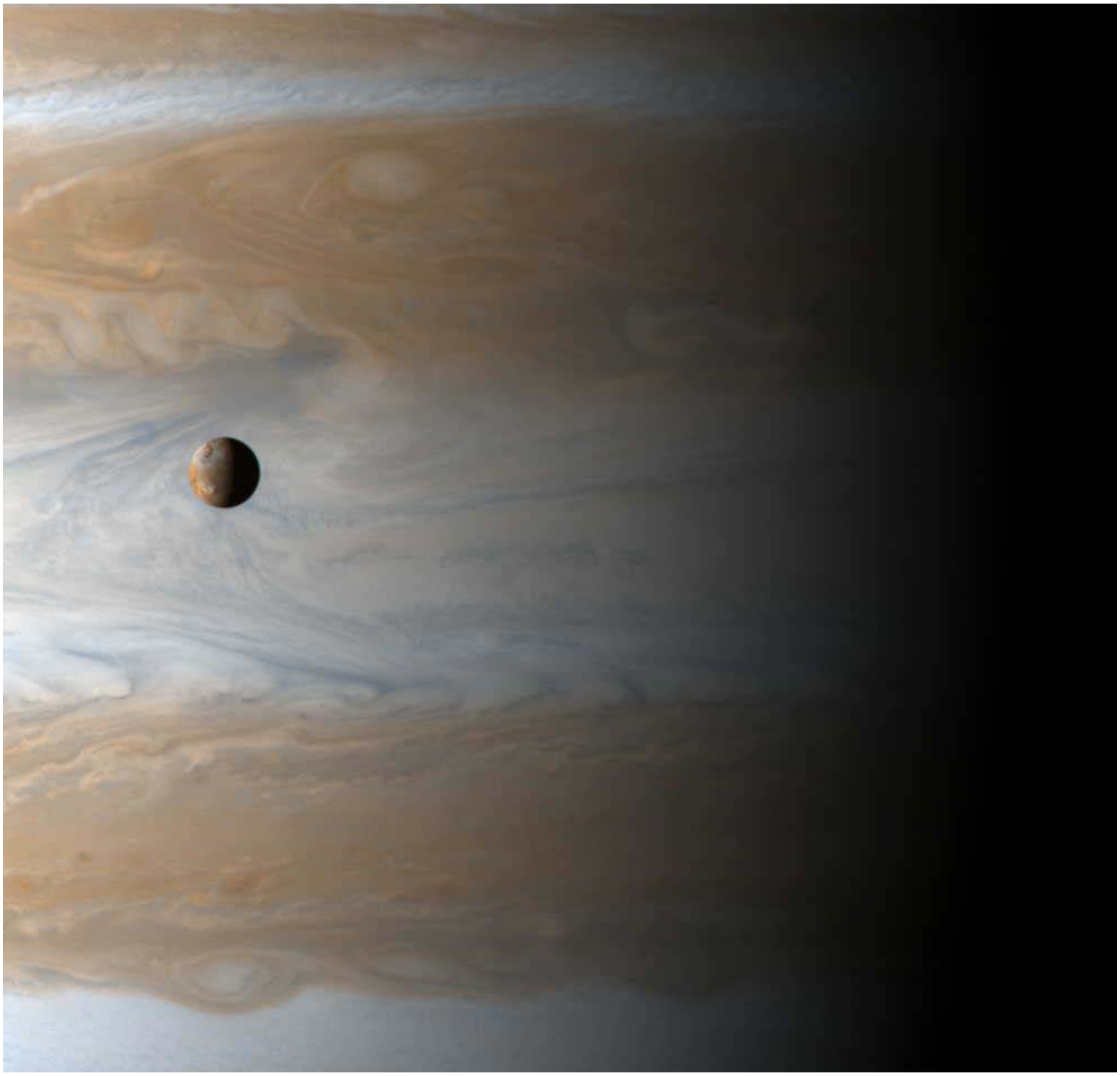
4.2 Science Themes

The Enterprise's broad research program comprises five Themes: Solar System Exploration, Mars Exploration, Sun-Earth Connections, Astronomical Search for Origins, and Structure and Evolution of the Universe. Each Theme aggregates related science objectives and activities, including flight missions and supporting research and technology development. The Themes are, in turn, managed by one of the three Enterprise divisions or a program office. These line organizations are responsible for managing the Enterprise's budget resources. Overlap and cross-fertilization of scientific questions and research does occur between Themes, an interaction that has proven to stimulate scientific innovation.

Within the Themes, definition, selection and management of supporting research and flight projects are carried out according to uniform Enterprise practices. Education and public outreach are considered an integral part of the Enterprise program, and all activities include a budgeted education or public outreach component.

The following section includes education and public outreach highlights, Objectives, and key technology requirements for each Theme. Missions and programs that are or will be in development over the period covered by this Strategy, that is 2003-2008, are named. . Additional candidate missions are also described; however, in recognition that scientific priorities evolve, this document implies no ordering for missions that could begin development after 2009.

4.2.1 Solar System Exploration



Solar System Exploration

Education and Public Outreach

Highlights

Formal Education Public Outreach

Future Plans

Our Solar System is a place of beauty and mystery, incredible diversity, extreme environments, and continuous change. It is also a laboratory that we can use to unlock mysteries of the origins of life and our place within the Universe. The planets and the ancient icy bodies that reside far from the Sun are Rosetta Stones that encode our own system's history and improve our understanding of the formation of other planetary systems and the prevalence of planets around other stars. Our Sun's planets have numerous moons with diverse characteristics, and each tells a story about the evolution of our Solar System. As we discover more about these moons, and about the origins of living systems, we may learn that life once arose or still exists on some of them. NASA's Solar System Exploration Theme has four Objectives.

Objective 1: Learn how the Solar System originated and evolved into its current diverse state.

Within the first billion years of their history, the planets of our Solar System formed and life began to emerge on Earth and, perhaps, elsewhere. Many of the current characteristics of the Solar System arose during this critical formative epoch. The tremendous changes that Earth and the planets have undergone over the intervening eons, however, have erased most of the physical records of this period. Our knowledge of it is only fragmentary.

Fortunately, vital clues are scattered throughout the Solar System. The Moon's South Pole Aitken Basin may offer the oldest rocks accessible for detailed geochemical analysis. The surface and environment of Mercury may yield clues to conditions in the innermost parts of the solar nebula and to the processes that formed the inner planets. The interior structure and chemical composition of Jupiter may illuminate the processes that formed the giant planets. The Pluto/Charon system and the Kuiper Belt, the most distant worlds in our Solar System, may have preserved the best records of the volatile and organic materials present in the original solar nebula. Also, the Kuiper Belt,

New Frontiers, a New Mission Line for Exploration

New Frontiers is a mission line dedicated to ambitious Solar System Exploration. The principal objective of the New Frontiers Program is to provide regularly scheduled opportunities for high-quality, cost-effective scientific investigations that fulfill the Solar System Exploration Objectives. In keeping with Enterprise practices, these missions will be competitively selected through peer-reviewed proposals.

Following the recent publication by the National Research Council of the Decadal Solar System Exploration Survey, entitled *New Frontiers in the Solar System: An Integrated Exploration Strategy,* the Space Science Enterprise identified five medium-class missions for immediate consideration for this first opportunity within the New Frontiers Program. These "strawman" missions are:

1) Kuiper Belt/Pluto
2) Venus *in situ* explorer;
3) Lunar South Pole Aitken Basin sample return mission;
4) Jupiter polar orbiter with probes; and
5) Comet surface sample return mission.

birthplace of the short-period comets, may have delivered volatile (*e.g.,* water) and organic materials to the inner planets. *MESSENGER*, a Discovery mission currently in development, will conduct comprehensive geophysical and geochemical investigations of Mercury. *Deep Impact*, another Discovery mission, will investigate volatile and organic materials in the deep interior of the nucleus of a short-period comet. *New Horizons*, the first New Frontiers mission, will address the highest-priority Decadal Survey science area: Pluto and the Kuiper Belt. *New Horizons* will characterize the global geology and morphology of Pluto and Charon; map their surface compositions, and characterize the neutral atmosphere of Pluto and its escape rate.

The underlying physical, chemical, geological and biological processes of the bodies in our Solar System interact in complex and surprising ways. For example, after the epoch of planet formation, the evolutionary paths followed by each of the inner planets led to dramatically different outcomes. Life flourished on Earth, while Mars rusted and Venus was consumed by radical greenhouse warming. We will study this interplay of processes to understand how they shaped the Solar System and can affect potential habitats for life. Comprehensive comparative studies of the atmospheric chemistry, dynamics, and surface-atmosphere interactions on Mars and Venus will yield insight into to the evolutionary paths these planets followed, and their implications for the Earth.

The exploration of our Solar System will tell us much about the formation of extrasolar planetary systems. Conversely, characteristics of extrasolar systems will also inform our understanding of our own home system—and may give us insight into how typical (or unique) our Solar System might be.

<u>Objective 2: Determine the characteristics of the Solar System that led to the origin of life.</u>

The essential requirements for life as we know it are basic nutrients, organic material, liquid water, and a source of usable energy. The availability of all of these ingredients defines what is called a "habitable zone." Scientists once thought that the habitable zone of our Solar System is limited, primarily by solar energy, to a fairly narrow region around Earth's distance from the Sun. On the Earth, habitable environments were thought to be limited to regions on or near the surface, where temperature, pressure and chemical conditions are favorable.

Discoveries made within the past few decades, however, have greatly expanded our view of the range of conditions capable of supporting life on our own planet. Scientists have discovered microbial life forms that survive, and even thrive, at high and low extremes of temperature and in extremes of acidity, salinity, alkalinity and concentrations of heavy metals that were once considered lethal. These discoveries on Earth, coupled with a fuller understanding of the range of possible conditions on other planetary bodies, have significantly expanded our view of the number of environments within our Solar System that might be, or might have been, conducive to life. We identify habitable zones in our Solar System based on this recent and ongoing research.

Research suggests that when the Earth formed, the inner solar nebula was too hot to retain the large quantities of water and organic materials seen in the current Earth environment. Instead, organics, water, and volatile materials probably condensed in the outer reaches of the solar nebula, where low temperatures favored their retention in comets. Subsequently, comet impacts may have delivered these essential ingredients to the forming inner planets. We expect to find that the planetary system we know today is strongly linked to these early mechanisms for transportation of volatiles and organics. To achieve this objective, we will focus on an inventory of the nature, history and distribution of organics and volatiles in the Solar System. The *Huygens* probe, a cooperative project with the European Space Agency now *en route* to Saturn aboard NASA's *Cassini* spacecraft, will characterize the murky and mysterious atmosphere of Saturn's moon Titan. The products and pathways of long-term organic evolution on Titan have important parallels to the origin of life on Earth. In addition, a potential New Frontiers comet-surface sample return mission would bring back a sample of organic material from the surface of a comet for detailed analysis.

> The *Jupiter Icy Moons Orbiter* would enable three important science activities:
>
> 1. Scout the potential for sustaining life on these moons. This would include determining whether the moons do indeed have subsurface oceans; mapping where organic compounds and other chemicals of biological interest lie on the surface; and determining the thicknesses of ice layers, with emphasis on locating potential future landing sites.
> 2. Investigate the origin and evolution of these moons. This would include determining their interior structures, surface features and surface compositions in order to interpret their evolutionary histories (geology, geochemistry, geophysics) and how this illuminates the understanding of the origin and evolution of the Earth.
> 3. Determine the radiation environments around these moons and the rates at which the moons are weathered by material hitting their surfaces. Callisto, Ganymede and Europa all orbit within the powerful magnetic environment that surrounds Jupiter. They display varying effects from the natural radiation, charged particles and dust within this environment. Understanding this environment has implications for understanding whether life could have arisen on these distant moons.
>
> A JIMO Science Definition Team has been chartered to define detailed science objectives and requirements that take the greatest advantage of technological advances. At a minimum, JIMO would meet all of the Europa Geophysical Orbiter objectives called out in the NRC's decadal survey and, most likely, far exceed them.

NASA is developing plans for an ambitious mission to orbit three planet-sized moons of Jupiter--Callisto, Ganymede and Europa--which may harbor vast oceans beneath their icy surfaces. NASA's Galileo spacecraft found evidence for these subsurface oceans, a finding that ranks among the major scientific discoveries of the Space Age. The mission, called *the* ***Jupiter Icy Moons Orbiter (JIMO)***, would orbit each of these moons for extensive investigations of their makeup, their history and their potential for sustaining life. The *JIMO* mission would also raise NASA's capability for space exploration to a revolutionary new level by pioneering the use of electric propulsion powered by a nuclear fission reactor being developed under Project Prometheus (see box below). This technology would not only make it possible to consider a realistic mission for orbiting three of the moons of Jupiter, one after the other, it also would open the rest of the outer Solar System to detailed exploration in later missions.

Objective 3: Understand how life begins and evolves.

To understand how life can begin on a habitable planet, it is essential to know which organic compounds are available and how they interact with the planetary environment. Geochemical synthesis is a potentially important source of organic compound and remains an important focus of research on this question. Laboratory simulations have recently demonstrated that relevant molecules can be synthesized in interstellar ices in a nascent solar system. Analyses of meteorites, interplanetary dust particles, and comets have shown that many chemical compounds essential to life processes are present in these bodies, supporting the hypothesis that these materials were delivered to Earth by comet and asteroid impacts. It is important to establish the sources of pre-biotic organic compounds and to understand their history in terms of processes that would take place on any newly formed planet. In addition, we will study Earth's geological and biological records to determine the historical relationship between Earth and its biosphere.

NASA currently supports research in these areas via its Astrobiology Institute and other grants in the Astrobiology Program, such as Exobiology/Evolutionary Biology Research and Analysis programs.

Objective 4: Catalog and understand potential hazards to Earth.

The effects of cosmic impacts on Earth were realized in the early 1980s, when the extinction of the dinosaurs was first associated with the impact of an asteroid at least ten kilometers in diameter. More recently, it has been estimated that impacts by asteroids as small as one kilometer in diameter could cause major climate perturbations and regional devastation. Furthermore, the direct effects of impacts by bodies as small as 100 meters could cause major damage on more-local scales. In 1908, the impact of a body about that size leveled 2000 square kilometers of forest near the Tunguska River, in Siberia. A similar impact on a modern city would take an enormous toll in lives and destruction. To assess the level of danger posed by such an occurrence, we plan to determine the inventory and dynamics of bodies that could pose an impact hazard to Earth. In addition, we will determine the physical characteristics of comets and asteroids relevant to any threat they may pose to Earth.

Dawn, a Discovery mission about to enter implementation, will conduct extensive geochemical and geophysical investigations of the Main-Belt asteroids Ceres and Vesta. Vesta has been identified as the source of the basaltic achondrite class of meteorites that impact Earth. The overwhelming majority of Near Earth Objects (NEOs) come from the Main Belt, so physical characterization of Ceres and Vesta is important for understanding the type of threat that NEOs pose.

The NEO Observation Program supports several teams of ground-based astronomers working toward a Congressionally mandated goal to discover, by 2008, at least 90 percent of the asteroids and comets, with diameters larger than 1 kilometer, whose orbits closely approach the Earth and to determine their orbits with sufficient accuracy to predict whether any of them pose a threat to Earth. Researchers are on course to meet this goal, and, so far, none of the objects studied has been found to pose a foreseeable threat to Earth. The program is studying the feasibility and cost of extending the NEO search to much smaller, more numerous, and fainter objects capable of causing regional destruction.

Key Technology Requirements for Solar System Exploration

Solar System exploration is a uniquely challenging endeavor. It requires us to send robotic vehicles across vast distances; furnish them with electrical power for propulsion, data acquisition and communication; place them in orbit around (or onto the surfaces of) bodies about which we may know relatively little; ensure that they survive and function in hostile environments; acquire and transmit data from these throughout their lifetimes; and sometimes bring the vehicles themselves safely back to Earth with samples.

The future Solar System Exploration missions described in this Strategy will demand progress in power and propulsion systems, telecommunications, entry/descent/landing, mobility, autonomy, and science instrumentation. For example, Project Prometheus (see box) is a response to the demand for high-performance, long-lived power supplies for extended missions that will carry advanced science instrumentation, high-power communications capabilities, and advanced electric propulsion. Increasingly, future missions will also demand spacecraft systems that tolerate severe environments.

Sample return missions will require enhanced handling and curation techniques and facilities. Also, to prevent contaminating other planets, new methods of microbe identification and spacecraft sterilization must be developed. For the latter, the solution is likely to be a combination of sterilization-tolerant spacecraft systems and more effective sterilization methods.

Project Prometheus, the Nuclear Systems Program will develop the means to fundamentally increase the power available to spacecraft, thereby revolutionizing our capability to explore the Solar System. Increased power for spacecraft means not only traveling farther or faster, but it also means exploring more efficiently with enormously greater scientific return. High levels of sustained power would permit a new era of Solar System missions designed for agility, longevity, flexibility, and comprehensive scientific exploration.

Project Prometheus focuses on research and development of nuclear electric power and propulsion systems, specifically radioisotope-based systems that make use of the heat produced by the natural decay of a radioisotope fuel along with reactor-based systems that make use of the heat produced by nuclear fission.

The Radioisotope Power Systems program focuses on improvements to the existing radioisotope thermoelectric generator (RTG) design and on development of the Stirling Radioisotope Generator. The Multi-Mission RTG will be developed to work in space and on planetary bodies with atmospheres such as Mars. The Stirling Radioisotope Generator offers the potential of much greater conversion efficiencies; e.g., 25% compared to 7%.

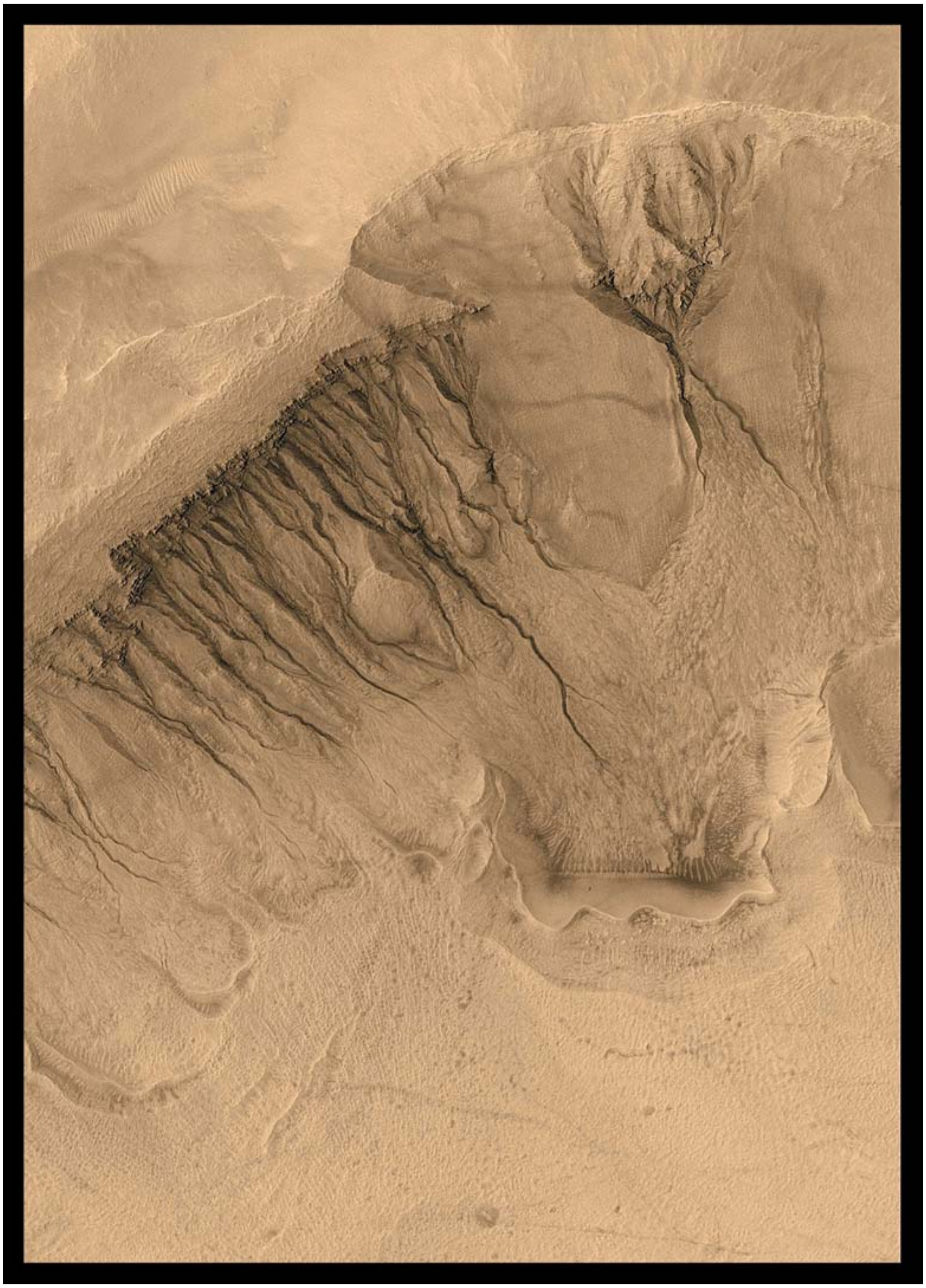
The Nuclear Power and Propulsion program will focus on research and development of a fission reactor designed to operate in space, advanced heat-to-power conversion technologies, and power management and distribution technologies. These technologies will enable a new paradigm in mission flexibility, long-duration missions, and orders of magnitude more power for science instruments.

Project Prometheus will include substantial involvement by the U.S. Department of Energy (DOE), which will be responsible for the nuclear systems development. NASA will define the science requirements that in turn will direct the systems requirements and mission design, resulting in technology development requirements to be met by the DOE. NASA Headquarters will directly manage the overall program with substantial participation by NASA Centers such as the Glenn Research Center, the Marshall Space Flight Center, and the Jet Propulsion Laboratory. A substantial portion of Project Prometheus research and development activities will be competitively awarded.

In addition, a range of technologies and system designs will be explored that may be prudent for NASA and DOE to invest in over the next several years, beyond the specific technologies already under consideration. NASA and DOE would also identify and recommend additional strategic technology investments to potentially enable future human exploration of the Solar System.

In keeping with NASA's goals of openness and transparency, Project Prometheus will seek to ensure open and inclusive dialogue and engagement with our stakeholders, the media, legislators, and others. Project Prometheus will also support education and public outreach programs.

4.2.2 Mars Exploration



Mars Exploration

Education and Public Outreach

Highlights

Formal Education

Public Outreach

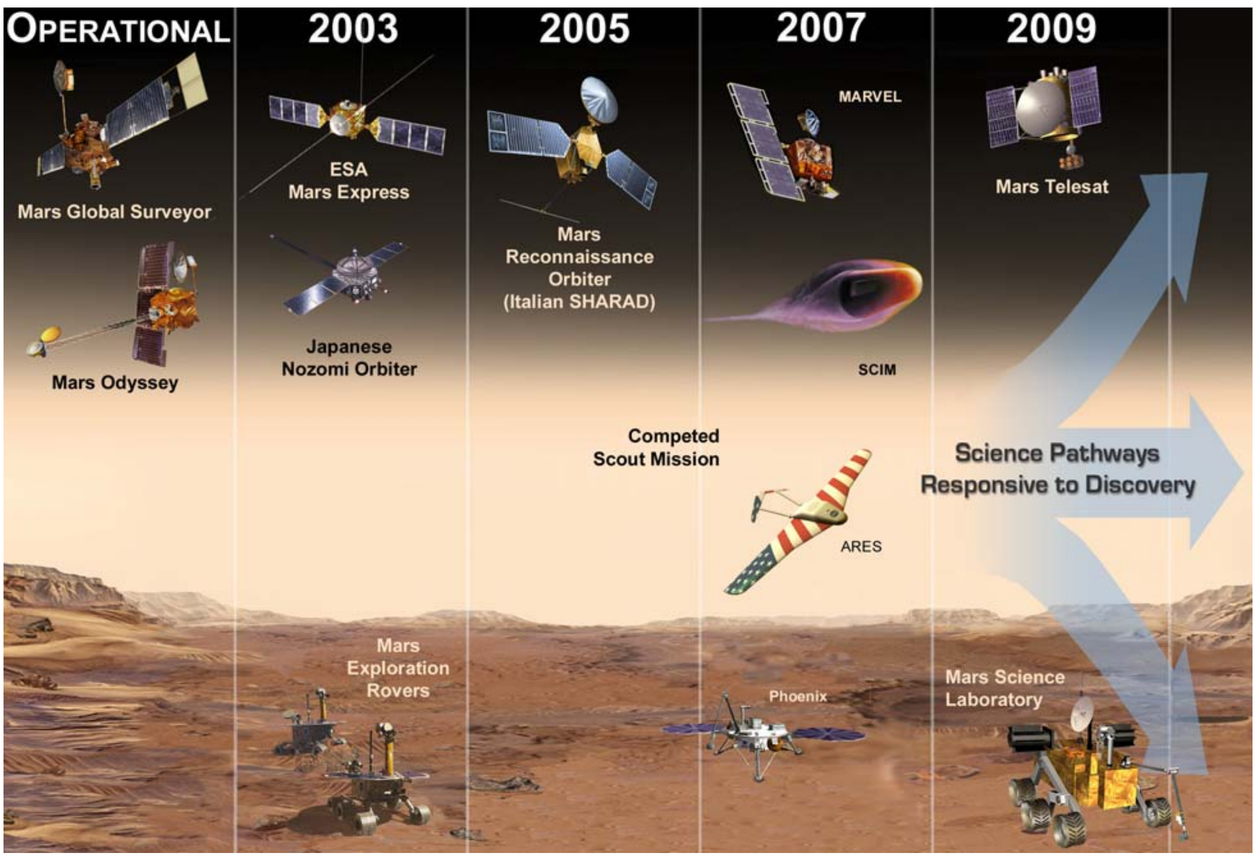
NASA and the Lego Co., a Denmark-based toymaker, with collaboration from the Planetary Society, Pasadena, Calif., sponsored a name the Mars Exploration Rovers contest. Of the nearly 10,000 entries, the winning essay was one by 9-year-old Sofi Collis.

Sofi wrote in her essay: "I used to live in an orphanage. It was dark and cold and lonely. At night, I looked up at the sparkly sky and felt better. I dreamed I could fly there. In America, I can make all my dreams come true. Thank you for the 'Spirit' and the 'Opportunity.'"

Collis was born in Siberia. At age two, she was adopted by Laurie Collis and brought to the United States. "She has in her heritage and upbringing the soul of two great spacefaring countries," NASA Administrator Sean O'Keefe said. "One of NASA's goals is to inspire the next generation of explorers. Sofi is a wonderful example of how that next generation also inspires us."

Future Plans

Mars holds a special place in the Solar System by virtue of its similarities to Earth, its potential for having been an abode for life, and its value as a "natural laboratory" for understanding the environmental and geological evolution of rocky planets. Mars is within our reach; we can most easily land on and probe this planet. The flood of new discoveries about Mars -- including those that pertain to the role and abundance of water, the character of global climate variability, and the tantalizing array of environmental niches that exist even today as potentially life-hospitable places -- has inspired a comprehensive, scientific campaign to understand the Red Planet. The overarching objectives focus on characterizing Mars, understanding its evolution and biological potential, and ultimately laying the groundwork for future human exploration that will extend our current campaign of robotic scientific exploration. By understanding the biological potential of Mars, we can apply this knowledge to other high-priority Solar System objects.



<u>Objective 1: Understand the current state and evolution of the atmosphere, surface, and interior of Mars.</u>

Understanding Mars's atmosphere, surface, and interior, and their interactions with one another can tell us much about the environment in which life could have developed and subsequently been preserved. Characterizing this unique interplay of systems on Mars —the atmosphere, surface, and interior—also bears directly on the search for evidence of life on planets elsewhere in the Universe.

NASA is planning a methodical succession of orbiting and surface laboratories over the next decade to progressively refine our understanding of the planet. In the near term, the *Mars Global Surveyor* orbiter will continue to characterize the dust and temperature properties of the martian atmosphere, document surface landforms that show evidence of liquid water erosion and climate change, and refine our knowledge of the interior by mapping Mars's magnetic field and gravity. Currently, the 2001 *Mars Odyssey* orbiter is mapping the elemental composition and mineralogy of the martian surface, as well as documenting aspects of its water cycle. The two 2003 *Mars Exploration Rovers* will make *in situ* observations of the chemistry, mineralogy, and mechanical properties of the surface materials on Mars at two locations where liquid water appears to have played a major role. Also launched in 2003, the NASA subsurface sounding radar on the European Space Agency (ESA) *Mars Express* orbiter will map the uppermost one to five kilometers of the martian crust in search of water-related layering and other fundamental subsurface structures.

Later in the decade, the 2005 *Mars Reconnaissance Orbiter* will characterize atmospheric processes over a full Mars year and provide the first definitive measurements of local mineralogy relevant to the role of liquid water on the surface. This orbiter will also document surface layering to clarify how the surface has evolved in association with standing bodies of water or other water-related processes. In 2007, a Mars Scout mission will augment the core program with a competitively selected investigation that will fill known and emerging measurement gaps related to the "habitability of Mars.” Subsequently, the 2009 Mars Science Laboratory will explore a compelling site on Mars's surface for evidence of organic materials and other diagnostic signatures of past or present life, including microscopic textures and associated chemistry. Additional missions for the 2011 and 2013 launch opportunities will be selected on the basis of new knowledge about Mars obtained during current and planned future investigations.

<u>Objective 2: Determine if life exists or has ever existed on Mars.</u>

The discovery of life, past or present, on Mars would be a defining moment for humankind. Evidence may come from the study of meteorites from Mars as well as exploration of Mars itself for biomarkers and other indicators of biological processes. NASA sponsors studies of Mars meteorites to detect the presence of chemical indicators of life or, at least, life-hospitable indicators such as water. In addition, NASA sponsors development of new sensors that will be able to search for evidence of organic materials *in situ* on Mars. Understanding the context for life at anytime or place on Mars is central to this activity. There may be present-day environmental niches on Mars that are life hospitable, as well as specific deposits that have favored preservation of organic materials. Chemical indicators of prebiotic activity are also connected to the question of whether life ever arose on Mars.

Orbital reconnaissance by the *Mars Global Surveyor*, *Mars Odyssey*, and the *Mars Reconnaissance Orbiter* will enable us to locate the highest-priority surface sites relevant to the search for life by identifying evidence for past or present water or by locating telltale minerals indicative of hospitable ancient environments. The *Mars Exploration Rovers* and *Mars Science Laboratory* will land on Mars and explore three sites for mineralogical and chemical evidence of the role of liquid water. The *Mars Science Laboratory* will seek organic materials or related biosignatures in the accessible surface layer. The 2007 Mars Scout mission will also contribute to the understanding of the habitability of Mars from alternate vantage points and unique experimental perspectives to complement other Mars missions.

<u>Objective 3: Develop an understanding of Mars in support of possible future human exploration.</u>

Focused measurements of the martian environment will help us identify potential hazards to human explorers and will allow us to inventory martian resources of potential benefit to future human missions. Missions over the next decade will characterize the distribution of water—as ice or liquid—both from orbit and from *in situ* analysis of local materials, as well as provide understanding of the space radiation environment in the vicinity of Mars.

The *Mars Global Surveyor* and *Odyssey* orbiters have already improved estimates of the abundance of water within the uppermost surface layer, atmosphere, and icecaps of Mars. The 2005 *Mars Reconnaissance Orbiter* mission will use sub-surface sounding radar to search as deep as hundreds of meters for evidence of layers associated with the presence of aqueous processes. The 2003 *Mars Exploration Rovers* will measure the martian surface mechanical properties, the magnetization of local materials, and the composition of specific rocks and soils. The 2009 *Mars Science Laboratory*, another landing mission, will emphasize characterization of organic and related molecules, as well as toxicity of soils. The *Odyssey* orbiter is presently measuring the galactic cosmic radiation background from the Mars orbit, and it is likely that solar and cosmic radiation measurements will be conducted from the Mars surface later in the present decade. The 2009 *Science Laboratory* mission will access the shallow subsurface to measure the presence of water and oxidants as a function of depth. Thus, by early in the next decade, a relatively complete inventory of critical environmental parameters, local hazards, and potential resources will be available to support future human exploration.

<u>Key Mars Exploration Technology Requirements</u>

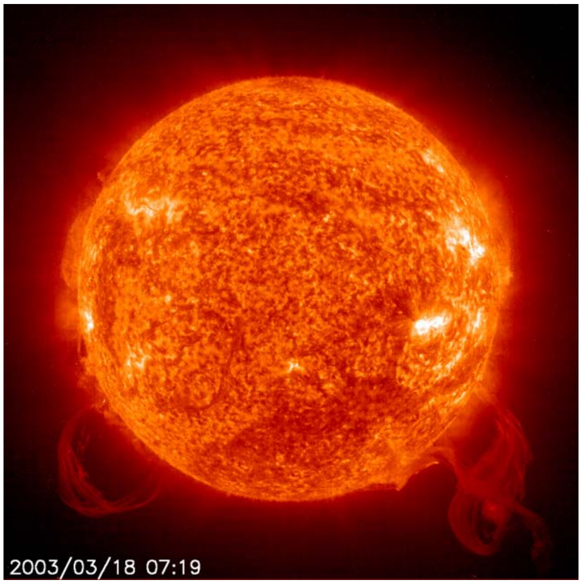
Comprehensive scientific exploration of Mars during the current decade and projected into the next requires unique technology investments and developments. Given the technology maturity required to make substantial headway in the understanding of the habitability of Mars, near-term investment in the following capabilities is needed:

- Precision, targeted access to the surface of Mars via improved Entry, Descent, and Landing systems (i.e., better than 10-kilometer horizontal precision).
- Access to the shallow subsurface of Mars to depths in excess of one meter.
- Enhanced lateral mobility systems that allow access to a greater breadth of materials for *in situ* analysis.

- Longer-lived surface power systems that provide for year-long surface operations at virtually all latitudes, independent of solar illumination.
- Improved *in situ* analytical instruments for precise measurements of key chemical indicators, presence of liquid water, and geophysical parameters.
- *In situ* sample acquisition, preparation, distribution, and handling necessary for definitive surface-based analyses of a full range of materials (rock, soil, dust, ices, gases, etc.)
- Ascent vehicle systems suitable for launch of carefully selected martian samples to Mars orbit.
- Airborne platforms suitable for obtaining regional to local scale observations not possible from surface-based vehicles.
- Penetrator-based landing systems with high-g tolerant instruments that provide access to high-priority sites with terrain too complex to land rovers.
- Systems necessary to return samples to Earth.
- New classes of instruments that can operate below the ground or ice surface of Mars for direct observations of unique materials and environmental conditions.
- Small, scientific stations on the martian surface suitable for developing a global planetary network for understanding the climate and interior of Mars.
- Active landing-hazard avoidance systems to facilitate precision landing even in more complex terrain.
- Automated orbital rendezvous systems needed for future Mars sample return missions.

These capabilities and the technologies associated with them are directly linked to planned and potential missions that will advance our knowledge of Mars as a system, as we explore the planet for evidence of its biological potential. In addition, the Mars Exploration Program will serve as a technology pathfinder for exploring other Solar System bodies. For example the 2009 *Mars Science Laboratory* requires unique capabilities for surface sample acquisition, handling, and preparation. These capabilities are vital to its mission as our next-generation landed laboratory, but will also serve other high-priority Solar System Exploration mission needs.

4.2.3 Sun-Earth Connection



Sun-Earth Connection

Education and Public Outreach

Highlights

Formal Education Public Outreach

Future Plans

Life on Earth prospers in a biosphere sustained by energy from the Sun. We are living with a star, constant in its energy when averaged over the millennia, yet highly variable on a 11-year cycle and, sometimes, from second to second. Our planet orbits within the inhospitable outer layers of this magnetically variable star's atmosphere. Fortunately, our Earth’s atmosphere and magnetic field shield us from dangerous radiation and particles coming from the Sun and the galaxy beyond. Still, powerful flares and coronal mass ejections aimed toward Earth can disrupt telecommunications and navigation, threaten astronauts, damage satellites, and disable electric power grids on Earth.

A Milestone in Exploring Sun-Earth Connections

We now have instruments in place to trace the flow of energy every step of the way from the Sun to our home planet. April 2002 marked a time of violent solar disturbances, including flares and coronal mass ejections (CMEs). For the first time scientists were able to link energetic particles accelerated in the flares and at CME-driven interplanetary shocks with measurements made upstream from the Earth, just before they reached the Earth’s upper atmosphere, and watch as they altered the atmosphere’s chemical composition. Scientists subsequently observed the CME’s interaction with the Earth’s magnetosphere—generating electric fields, accelerating atomic particles, and heating the upper atmosphere. These atmospheric fireworks cause brilliant auroras also known as “Northern lights.”

This linked chain of observations required a combination of measurements from SEC and partner-agency satellites, including one new STP mission, six Explorer satellites, one NASA/ESA mission, and several satellites in extended missions.

With the suite of near- and mid-term missions described in this strategy, NASA will be able to probe the very origin of the solar wind, explore the causes of solar activity, track the propagation and evolution of solar ejections through interplanetary space, and explore the consequences of solar activity for magnetospheric storm development and resultant effects on the radiation belts, ionosphere, and upper atmosphere on Earth. The detailed physical processes that enable the transfer of energy across the Earth’s magnetic barrier and through the geospace system will be probed, and the implications for human society will be clarified.

The region of space influenced by the Sun, called the heliosphere, extends beyond the planets and ends where the solar wind encounters the interstellar medium at our Solar System’s edge. We are just beginning to understand the physics of space weather, the diverse array of dynamic and interconnected phenomena that affect both life and society. Understanding space weather effects becomes more important as the government and private sectors increasingly rely on space- and ground-based assets subject to the influences of the space environment.

The Sun provides the most accessible laboratory to study the structure and evolution of stars and stellar systems. Knowledge of long-term variability of solar activity is important because of its effects on planetary atmospheres, the radiation and energetic particle environment, planetary surfaces, and therefore the development of life. The elements of this stellar-planetary system are highly interlinked. Continued progress in understanding them will require theory, modeling, and data analysis that cross traditional discipline boundaries.

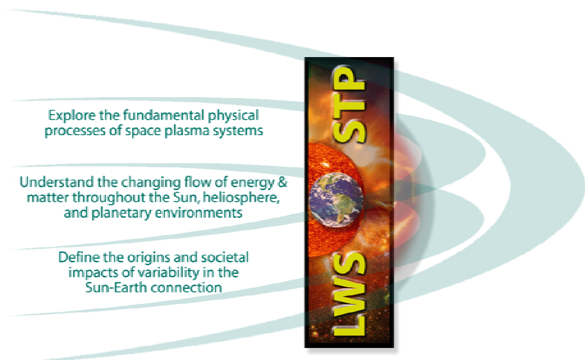
The aim of the Sun-Earth Connection (SEC) Theme is to understand the Sun, heliosphere, and planetary environments as a single connected system. The SEC science Objectives and strategic missions are closely aligned with the challenges and priorities in the NRC's *The Sun to Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*. Of the NASA-related programs recommended in the survey, the only large program, all of the moderate programs, all but the lowest-ranked of the small programs, and the vitality program recommendations are addressed in this Strategy. The SEC 2003 Roadmap outlines the future of the SEC Theme. Science Objectives are presented and prioritized, and the programs and missions necessary to achieve these objectives are identified.

[Insert Mary Pat's timeline]

The SEC strategic missions reside in the Solar Terrestrial Probes (STP) or Living With a Star (LWS) program lines. The STP missions address fundamental science questions about the physics of plasmas and the flow of mass and energy in the Solar System (Objectives 1 and 2, below). By contrast, the LWS missions are designed to develop specific knowledge and understanding of those aspects of the connected Sun-Earth system that directly affect life and society. LWS missions are associated primarily with Objectives 1 and 3.

A range of ongoing flight programs, including the Explorer and suborbital programs, supplements these strategic mission lines. Both of these programs provide opportunities for sharply focused attacks on strategic science objectives as well as on newly emerging science questions. In addition, SEC pursues opportunities for collaborative missions with other themes and agencies, including foreign space agencies.

[Include LWS/STP objective figure for a visual reference – see below]



The three primary science objectives of the SEC Division and their relationship to the Solar Terrestrial Probe (STP) and Living With a Star (LWS) missions

<u>Objective 1: Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.</u>

At one end of the causal chain, we have questions about the structure and dynamics of the Sun, its corona and solar wind, and the origins of magnetic changes in the Sun. At the opposite end, we need to determine how the variable heliosphere interacts with the interstellar medium at the heliopause, which is the outer boundary of the Solar System. Between the Sun and heliopause orbit the Earth and all the planets. Understanding how their unique magnetospheres and atmospheres respond to both internal and external drivers will help explain the behavior of our own planet. This broadest Theme Objective includes research focus areas appropriate to both STP and LWS missions.

Two relevant STP missions are already in development. *Solar-B*, a Japanese-led mission with significant NASA participation, will reveal how the Sun's photosphere is magnetically coupled to the corona and will track the life cycle of small magnetic regions at the solar surface with high-resolution solar telescopes. The Solar TErrestrial RElations Observatory (*STEREO)* will for the first time determine how coronal mass ejections (large solar storms) begin and how they propagate towards Earth. *STEREO's* two spacecraft in solar orbit will move gradually ahead of and behind the Earth to provide stereoscopic views of evolving features in the solar atmosphere, giving us a 3-D view never seen before.

Geospace Electrodynamic Connections (GEC) is a subsequent STP mission to investigate how the Earth's ionosphere-thermosphere system responds to the variations in the overlying magnetosphere; it features a string of spacecraft in a very low-perigee orbit, measuring *in situ* conditions.

Currently under study but not yet in the budget, *Solar Probe* would make the first voyage to a star, plunging to within two million miles of the Sun's surface. This ambitious mission would fly through the solar atmosphere to answer fundamental questions that can be answered in no other way. *Solar Probe* would determine the acceleration processes and source regions of fast and slow solar wind that streams into space. The mission would also locate the source and trace the flow of energy that heats the corona to over three million degrees, much hotter than the Sun's surface. This journey to the Sun poses special technological challenges because of the extreme and unexplored environment. *Solar Probe* received highest priority in the National Research Council's Decadal Survey of solar and space physics research.

Later STP mission concepts include: a constellation of several dozen nanosatellites in the Earth's magnetotail to understand the regulation of energy in the magnetosphere; a probe to measure the polar regions of the Sun and the heliosphere from high solar latitude; a two-spacecraft mission to determine how small-scale waves in the Earth's upper atmosphere couple to its lower atmosphere; a stereoscopic magnetospheric imager to reveal the dynamic global structure of the plasmasphere, ring current, radiation belts, and the auroral regions; and a deep space probe to remotely image the boundaries of the heliosphere by detecting interstellar neutral atoms and radiation.

<u>Objective 2: Understand the fundamental physical processes of space plasma systems.</u>

This Objective spans many astrophysical problems and relies primarily on STP missions. One focus area is to discover how solar magnetic fields are created and evolve and how they produce heat and high-energy particles. Mechanisms for creating, destroying, and reconnecting magnetic fields are key to many Sun-Earth Connection problems—solar activity, geomagnetic activity, the heliospheric boundary, and most forms of particle acceleration. The other space plasma research focus area involves understanding how and why processes that occur on very small scales generally affect large-scale global dynamics. This coupling across multiple scale lengths is important for understanding instabilities and turbulence in all space plasmas. The solar system offers the opportunity to test the scientific understanding of these processes in diverse plasma environments.

In the near term, the Magnetospheric Multi-Scale STP mission will measure reconnection, turbulence, and particle acceleration at small and intermediate scales using a small cluster of spacecraft to explore key magnetosphere locations. Also in the near term, potential collaboration on the European Space Agency's (ESA's) *Bepi-Colombo* mission to Mercury may enable detailed exploration of a planetary magnetosphere that lacks an ionosphere.

Future exploration may focus on Jupiter's auroral regions. Imaging and *in situ* data from such a mission, perhaps developed jointly with the Solar System Exploration Theme, would show magnetospheric processes operating under vastly different conditions from those on Earth. Another future mission may focus on magnetic reconnection and micro-scale processes in the solar atmosphere using both high-resolution spectroscopy and imaging.

<u>Objective 3: Understand the origins and societal impacts of variability in the Sun-Earth connection.</u>

This Objective has the most immediate relevance to society and relies primarily on LWS missions. Two research focus areas concern space weather variations on the scales of hours and days. The first relates to disturbances that travel from Sun to Earth, such as radiation and immense clouds of magnetized material that can damage telecommunication satellites, knock out ground-based power grids, and affect the health of astronauts. This involves monitoring the Sun and developing-the capability to forecast solar activity and predict the evolution of structures as they move through the heliosphere. The second involves development of the capability to specify, and ultimately predict, changes to the Earth's radiation environment, ionosphere, and upper atmosphere. On longer time scales, human society has a real need to understand the role of solar variability in driving global change in Earth's atmosphere and space climate. These three areas are addressed in three ways: by the LWS Targeted Research and Technology Program, which will also speed the transition of space weather understanding to routine operations; by the LWS Space Environment Testbeds (SET) Program, which will help us learn how to mitigate the effects of solar variability on spacecraft; and by the investigations supported by the missions described below.

[Insert radio blackout image]

In the near term, the LWS *Solar Dynamics Observatory* (SDO) will observe the solar interior and atmosphere continuously from geosynchronous orbit to determine the causes of the solar variability that affects Earth. Its imagers will provide global views with four times the resolution of those currently available. Coordinated observations from the two pairs of LWS Geospace Storm Probes will link the solar and geospace systems. The *Ionospheric-Thermospheric Storm Probes* will determine the causes of ionospheric variability and irregularities at middle latitudes that affect communications. The *Radiation Belt Storm Probes* will determine how the radiation belt particles that affect astronauts and spacecraft performance are injected, accelerated, distributed, and eventually lost.

The next likely LWS mission requires sentinels in the inner heliosphere to measure how changing conditions inside the Earth's orbit affect propagation of solar emissions directed toward Earth. ESA's *Solar Orbiter* may offer an opportunity for partnership on one of the sentinels as part of the International Living with a Star (ILWS) Program. Subsequent mission candidates include

- A constellation of small spacecraft in the inner magnetosphere to identify how the coupling between the Earth's radiation belts, ring current and plasmasphere produces energetic particles;
- a mission to discover how the low-latitude coupling of the upper layers of the atmosphere—mesosphere, thermosphere, ionosphere, and plasmasphere—affects communications;

- A cluster of simple *in situ* probes held by solar sails, hours upstream from Earth in the solar wind, to measure the transient structures that will impact the Earth; and
- A high-resolution investigation of the dynamics of the solar transition region that controls the stability of larger-scale structures.

Key Sun-Earth Connection Technology Requirements

Progress in four key technology areas is vital for SEC's planned mid- and long-term missions:

- Spacecraft systems for affordable clusters and constellations of small, ultra-low-power satellites providing multi-point measurements of the connected Sun-Earth System.
- Information technology that will allow ready access to and analysis of an unprecedented volume of data from multiple spacecraft in diverse locations and improved spacecraft autonomy to reduce spacecraft operations costs.
- Scientific instruments with improved remote sensing and *in situ* measurement capabilities including speed, precision optics, collecting area, sensitivity, energy resolution, and angular resolution; also very lightweight, low-power instruments.
- Solar sails and other advanced propulsion systems that allow spacecraft to remain at crucial vantage points, such as hovering upstream in the solar wind, or to explore "uncharted" regions such as the Sun's poles, a near-solar heliosynchronous orbit, and the interstellar medium.

4.2.4 Astronomical Search for Origins

Education and Public Outreach

Highlights

Formal Education Public Outreach

Future Plans

The Origins theme focuses on two questions: “Where did we come from?” and “Are we alone?” While these questions are relatively simple, the scientific and technical challenges to answer them are complex. Today the Universe is full of structure, from giant but simple galaxies to minuscule but complex single living cells. Our objective is to understand how this astronomical structure came about, how stars and planets form, how the chemical elements are made, and ultimately how life originates.

<u>Objective 1: Understand how today’s Universe of galaxies, stars and planets came to be.</u>

Research on this Objective aims to determine how the cosmic web of matter that emerged from the Big Bang organized into the first stars and galaxies, how different galactic ecosystems of stars and gas form, and which of these ecosystems can lead to planets and living organisms.

About 250 million years after the Big Bang, what had been a calm, near formless sea dark matter and hydrogen gas began to surge with the froth of complex forms of matter and energetic processes. The *Wilkinson Microwave Anisotropy Probe* (*WMAP*) has shown that star formation began before there were galaxies, and that when these early stars died explosively as supernovae, they produced the first spray of heavy elements. But it also appears that the birth of galaxies -- by binding the stars and gas together to create great cosmic ecosystems -- was crucial to the buildup of these heavy elements to a level where planets and life became possible. The key steps on the road to life were the emergence of such enormous structures from the formless Universe and the manufacture of vast amounts of heavy elements by stars.

We intend to investigate how the diversity of galaxies in today's Universe emerged from the assembly of the first galaxies and the subsequent evolution of their stars. We will also learn how the lifecycle of stars led to the chemical elements needed for planets and life, as well as determine if there is a region in our Galaxy that is especially suited to the development of life: a galactic habitable zone. By looking to ever-increasing distances, astronomers can essentially travel back through time to witness these crucial steps in our origins. Both present and planned facilities—the *Hubble Space Telescope* (*HST*), the *James Webb Space Telescope* (*JWST*), the *Space Infrared Telescope Facility* (*SIRTF*), and the *Stratospheric Observatory for Infrared Astronomy* (*SOFIA*)—will be used to study the formation of the earliest stars and heavy elements and to study how the formation of early black holes influenced the structure of the early Universe.

Direct detection of the first generation of stars will almost certainly require the unprecedented sensitivity of the Webb telescope. Observations with the Hubble and Webb telescopes of high-redshift star formation (that is, exceedingly distant and thus early) and galaxies with supermassive black holes powering bright cores, called active galactic nuclei, will allow us to trace the buildup of galaxies over time. Observations by the SIRTF and Webb telescopes will be crucial for tracing the energy budget of galaxy formation and early evolution. *SIRTF* will also characterize the large-scale infrared properties of 75 nearby galaxies to correlate star formation rates with properties of the interstellar medium.

Origins Missions Box:

Hubble Space Telescope – Perhaps the only telescope that is a household name, this 2.4-meter telescope collects images and spectra in the visible wave band, like our eyes, and also partially in the infrared and ultraviolet bands to study the formation and evolution of galaxies, stars, and planetary systems throughout the local Universe.

Space Infrared Telescope Facility – This 0.85-meter cryogenic telescope in solar orbit aims at understanding structure and composition of molecular clouds and the early stages of star and planet formation.

Stratospheric Observatory for Infrared Astronomy – A 2.5-meter telescope flying on a modified Boeing 747 collecting data on the properties of the clouds of gas and dust that lie between stars in our galaxy.

Kepler – A photometric survey telescope in space, selected in the Discovery program, to survey the extended solar neighborhood to detect and characterize planets down to Earth size.

Space Interferometry Mission – A 10-meter baseline optical interferometer in solar orbit looking for evidence of Earth-sized planets around nearby stars.

James Webb Space Telescope – An infrared telescope, with at least a 6-meter diameter, in solar orbit aimed at exploring the earliest galaxies.

Terrestrial Planet Finder – An infrared interferometer or visible-light coronagraph to directly detect and characterize potential atmospheres of planets like Earth.

<u>Objective 2: Learn how stars and planetary systems form and evolve.</u>

This Objective will focus on tracing the path of gas and dust to stars and planets, detecting planetary systems around other stars, and understanding planetary systems' architectures and evolution.

During the past three decades, we have used both ground- and space-based facilities to look inside the nurseries where stars and planets are born. Parallel studies of the Solar System, conducted with planetary probes, and of meteorites have revealed clues to the processes that shaped the early evolution of our own planetary system. An overarching goal of science in the 21st century will be to connect what we observe elsewhere in the Universe with objects and phenomena in our own Solar System.

Astronomers have now identified the basic stages of star formation. The process begins in the dense cores of cold gas clouds (molecular clouds) that are on the verge of gravitational collapse. It continues with the formation of protostars, infant stellar objects with gas-rich dusty circumstellar disks that evolve into adolescent "main-sequence" stars. Tenuous disks of ice and dust can remain after most of the disk gas has dispersed and surround these more-mature stars. In these last stages of star formation, planets are born.

In pursuing this Objective, we will investigate how molecular clouds act as the cradles of star and planet formation. We will determine how proto-planetary dust and gas disks mature into planetary systems, and search for evidence of planets in the disks around young stars. We will conduct a census of planetary systems around stars of all ages.

SIRTF then *SOFIA*, and possibly a future larger telescope, will be the first missions to determine the temperature, density and velocity structure of molecular clouds. The *Webb Telescope* will be able to probe the most central regions of protostars. High-angular-resolution studies in the near infrared with the *Webb Telescope* and SIRTF and in the far infrared with *SIRTF* and *SOFIA* are necessary to trace the distribution of important planetary constituents such as water, ice, silicates, and complex carbon molecules in the disks around young stars. *SIRTF* will provide the first hints about gas and dust dispersal; larger telescopes such as the *James Webb Space Telescope* are ideally suited to track the evolution and map the structure of vestigial debris disks around nearby main-sequence stars.

The *Terrestrial Planet Finder* (*TPF*) will be essential to distinguish between starlight and planetary radiation from the surrounding disk to possibly enable direct imaging of young protoplanets.

<u>Objective 3: Understand the diversity of other worlds and search for those that might harbor life.</u>

Toward the ultimate goal of finding life beyond our Solar System, we ask what are the properties of giant planets orbiting other stars, how common are terrestrial planets, what are their properties, which of them might be habitable, and is there life on planets outside the Solar System?

After centuries of speculation, we finally know that there are indeed planets orbiting other stars. The extrasolar planets discovered so far seem to be gas giants like Jupiter. Earth-like worlds may also orbit other stars, but until now our measurements lack the precision needed to detect a world as small as the Earth. Detection of Earth-sized planets could happen before the end of the decade through a Discovery mission, *Kepler*. Even before then, detailed studies of giant planets will tell us much about the formation and history of planetary systems, including our own. We have already made a first reconnaissance of the atmospheric properties of one such giant planet that passes directly in front of its star and allows us to probe its atmosphere, even if we can't see the planet directly.

The *Kepler* mission, surveying a myriad of distant stars, will be our first opportunity to find out how common it is for a star to have an orbiting Earth-sized planet. We will also learn how big these planets are and where they are located in relation to their stars' "habitable zones" where life as we know it is possible.

The flagship mission to carry forward the search for Earth-like worlds will be the *Terrestrial Planet Finder*, which will image nearby planetary systems and separate the extremely faint light of a terrestrial planet from its parent star.

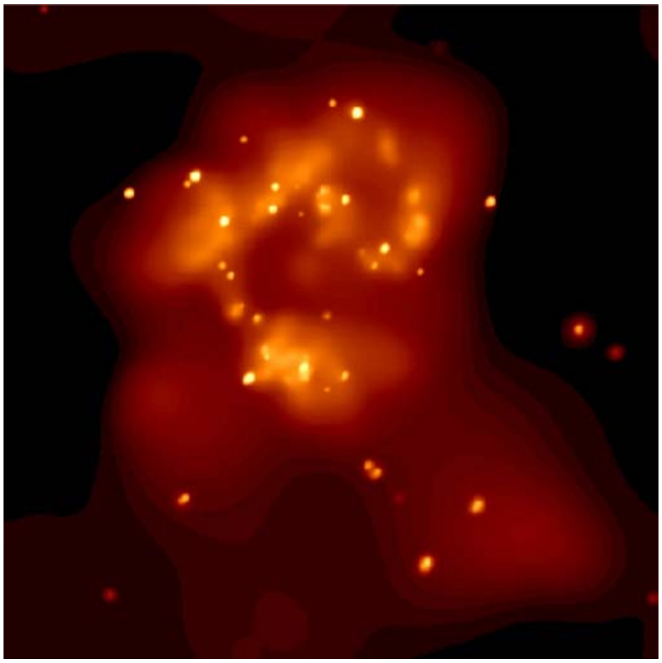
Once we have found terrestrial planets orbiting nearby stars, we can then tackle two even more ambitious objectives: to determine which of these planets actually have conditions suitable for life and which, if any, actually show signs of past or present life. Studies are underway to learn which "biosignatures"—identifiable spectral features in a planet's reflected light—can reveal past or present life on a planet. However, to take advantage of this new information, it will be necessary to develop space telescopes of unprecedented size and sophistication.

Key Astronomical Search for Origins Technology Requirements

The Origins technology plan has two strategic objectives. In the near term, the maturing technologies for observatories like the *Space Interferometry Mission*, the *James Webb Space Telescope*, and the *Terrestrial Planet Finder* must be completed and tested. These technologies include precision metrology and microdynamic disturbance reduction; rapid lightweight mirror panel fabrication and folded mirror deployment and alignment; and coronographic and advanced interferometric techniques.

For the longer term, it is critical to begin establishing the new technological building blocks for very large space observatories to follow. These observatories will require advances in four key areas: large lightweight mirrors for all wavelengths, active systems for precise control of optical elements, new detectors to improve the efficiency of collecting radiation, and cooling technologies to minimize the infrared radiation from warm telescopes.

4.2.5 Structure and Evolution of the Universe



Education and Public Outreach

Highlights

Formal Education

The Structure and Evolution of the Universe Theme has produced numerous activities for use in the classroom, introducing children to the fascinating world of black holes, neutron stars and astrophysics. The Swift mission created "The Invisible Universe, from Gamma Rays to Radio Waves," a Great Explorations in Math and Science guidebook for grades 6-8. This guidebook uses a series of standards-based classroom activities to teach students about the size and scale of cosmic explosions using the concept of waves. The *Gamma-ray Large Area Space Telescope* (*GLAST*) mission produced an activity guide that uses active "black-hole-powered" galaxies to teach students about angles, distances, and other math and science concepts.

Ten nationally selected "Educator Ambassadors" have helped to develop and test many of these activities, conducting national and regional training workshops using these materials with over 4,000 teachers in 20 different states, during the past year.

Public Outreach

Cosmic Questions: Our Place in Space and Time is a traveling museum exhibition that invites visitors to explore fundamental questions and gain an understanding of recent discoveries about the origin, evolution, and structure of the Universe.

Nine NASA space science missions, 14 major science institutions or universities— including the National Science Foundation and Boston Museum of Science—and dozens of space scientists contributed scientific expertise as well as data, images, and artifacts from space-science missions.

During its 2002 opening run at the Boston Museum of Science, *Cosmic Questions* had more than 350,000 visitors. Another 3 million visitors are anticipated in the 10 cities that *Cosmic Questions* will visit through 2005.

SEU Future Plans

The universal appeal of SEU cosmic questions offers an opportunity to bring the excitement of cosmic exploration into the nation's classrooms. Exploring the size and shape of the Universe, examining evidence for the Big Bang and black holes, and, most important, tracing the underlying idea that scientific inquiry can address even the most ancient and difficult questions, are key topics in the *National Science Education Standards*.

As future missions weave the ongoing story of cosmic evolution, accompanying educational efforts share that story with teachers through professional development opportunities and curriculum enhancement materials tied to the national standards. In this manner, this NASA Theme will soon provide the *majority* of materials on these subjects in our nation's schools.

In the Structure and Evolution of the Universe Theme, we seek to explore and understand, at the most fundamental level, the dynamic transformations of energy in the Universe, from the beginning of time to the present day and beyond and to study the entire web of interactions that determine the evolution of our cosmic habitat. Existing and proposed SEU missions directly address several of the "Eleven Science Questions for the New Century" posed by the NRC's *Connecting the Quarks with the Cosmos* report. These include: What is the nature of the "dark energy"? How did the Universe begin? Did Einstein have the last word on gravity? How do cosmic accelerators work? How were elements from iron to uranium made?

The Theme comprises two science programs: the new *Beyond Einstein* Program, the Theme's highest priority, and the *Cycles of Matter and Energy* Program. Both programs envision a suite of missions to achieve their science objectives. The *Beyond Einstein* program (see box) is dedicated to answering the most fundamental questions that one can ask about our Universe: How did the Universe begin? What is its ultimate fate? Is there a beginning to time? Does space have edges? How did the Universe evolve over the eons from its initially formless state to its present complex structure?

The *Cycles of Matter and Energy* program, the second of this Theme's two science programs focuses on our dynamic Universe. The Universe we see today is a very dynamic one: Stars are born, and stars die, either with the explosive demise of a supernova, or the lingering, cold death of a white dwarf. Galaxies evolve, collide, and become transiently bright beacons seen across the entire universe. The patterns of exchange of matter and energy dictate the creation of solar systems and life itself.

<u>Objective 1: Discover what powered the Big Bang and the nature of the mysterious dark energy that is pulling the Universe apart.</u>

Einstein's General Theory of Relativity predicted the expansion of the Universe. But we still have not determined the motive force that helped power the Big Bang and made our Universe as large as it is, allowing stars and galaxies to form and life to evolve. Einstein's theory also predicted the presence of a ubiquitous, invisible energy that causes the Universe to accelerate, but we have yet to begin to understand the origin and nature of this dark energy.

The inflationary universe theory explains how the Universe grew from being very small to very large within the first, tiny fraction of a second of its existence. This theory also predicts that we can directly view this birth of the Big Bang by looking at the gravitational radiation—wavelike ripples in spacetime—that was produced then and continues to propagate through the Universe now. Gravitational radiation may uniquely allow us to see back to the first tiny fraction of a second in the age of the Universe. Evidence for inflation can also be found through subtle patterns in the cosmic microwave background, the universal sea of low-energy photons produced when electrons and protons first combined to form neutral hydrogen approximately 400,000 years after the Big Bang.

Beyond Einstein

Einstein and his successors, in their attempts to understand how space, time, and matter are connected, made three predictions: First, space is expanding from a Big Bang; second, space and time can tie themselves into contorted knots called "black holes" where time actually comes to a halt; third, space itself contains some kind of energy that is pulling the Universe apart. These predictions seemed so fantastic that Einstein himself regarded them as unlikely, yet they have turned out to be true. But Einstein's theory alone cannot answers such questions as (1) What powered the Big Bang? (2) What happens to space, time, and matter at the edge of a black hole? or (3) What is the actual nature of the mysterious dark energy pulling the Universe apart? For this, we need to go beyond Einstein, to explore new theories that predict unseen dimensions and entire universes beyond our own. This is the quest of the *Beyond Einstein* missions, to help usher in the next revolution in understanding our Universe with crucial investigations that can be done only in space.

The *Beyond Einstein* mission line has two *Einstein Observatories*: the *Laser Interferometer Space Antenna*, a deep-space-based gravitational wave detector that will open our eyes to the as-yet unseen cosmic gravitational radiation; and *Constellation-X*, which through X-rays will tell us what happens to matter at the edge of a black hole. Three moderate-sized, scientist-led probes will answer, "What powered the Big Bang?" (an inflation probe), "How did black holes form and grow?" (a black hole finder probe), and "What is the mysterious energy pulling the Universe apart?" (a dark energy probe). The final element is a program of technological development, theoretical studies, and education and public outreach, supporting the mission line and pointing towards two Vision Missions: a Big Bang observer and a black hole imager. The Vision Mission goals are respectively to directly detect gravitational waves from the earliest moments of the Big Bang and to map the motion of matter near the edge of a black hole.

The *Beyond Einstein* missions will connect humans to the vast Universe far beyond the Solar System. They will extend our senses beyond what we can imagine today: to the largest and smallest things, the beginnings and ends of time and space. The images and knowledge gained in this quest will inspire all humanity—as only NASA can.

After its early and brief period of inflation, the Universe has continued to grow in accordance with Einstein's theory of gravity. The growth, shape, size, and destiny of the Universe are determined by a tug-of-war between visible matter, dark matter, and dark energy. Visible matter comprises only about 4% of the Universe, while dark matter makes up about 23% and dark energy makes up about 73%. We still do not know the nature of 96% of the content of the Universe! The newly discovered dark energy, a repulsive, anti-gravity type of force whose origin is a complete mystery, dominates the evolution of the Universe today, accelerating the expansion rate, sending galaxies farther and farther apart.

The *Laser Interferometer Space Antenna (LISA)* will measure gravitational radiation generated by a variety of astrophysical phenomena, including merging black holes and stars falling into supermassive black holes. It will also measure the effect of dark energy on the Universe by determining precise distances to sources of gravitational radiation. *LISA*, to be undertaken jointly with the European Space Agency, will also search for gravitational waves created during the earliest moments of the Big Bang, that could allow us to see back nearly to time's origin.

Constellation-X will constrain the nature of dark matter and dark energy by observing their effects on the formation of clusters of galaxies. Visible matter is attracted to the gravity of filaments of dark matter that thread the Universe, creating its web-like structure. Hydrogen gas falls onto these filaments and heats to high temperatures, glowing brightly in X-ray light like jewels on a necklace.

A dark energy probe will investigate the expansion rate of the Universe over the last several billions of years. Since dark energy has dominated the Universe's energy content during this time, we can learn from this whether dark energy is constant or varying over time. If it is constant, then dark energy is an energy that comes from the vacuum of space itself. If not, then it may show signs of a richer structure predicted by string theory, in which spacetime has more dimensions than we perceive with our senses.

In a manner completely complementary to LISA (above), an inflation probe will seek the imprint of primordial gravitational waves on the relic cosmic microwave background. This will test inflation theory of the very early Universe and will also test physics at energies that are currently inaccessible by any other means.

<u>Objective 2: Learn what happens to space, time, and matter at the edge of a black hole.</u>

The greatest extremes of gravity in the Universe today exist at the edges of black holes. Matter captured by the strong gravity of a black hole falls inward, accelerating to speeds close to that of light. This infalling gas, including that of stars shredded by the intense gravity fields, heats up dramatically, producing large quantities of X-ray radiation which can be used to study what happens near the edge of a black hole, where time comes to a standstill and matter disappears from view forever. By measuring such X-rays, we can observe the slowing of time near the surface of a black hole, as Einstein predicted, and investigate how infalling matter releases energy near its surface. We can also observe the evolution of black holes in distant galaxies and quasars, and determine their role in the evolution of their host galaxies.

When neutron stars or stellar-mass black holes fall into a supermassive black hole, they generate ripples in spacetime, called gravitational waves. By observing the waveforms of these ripples we can map the knotted structure of space and time around a black hole, and determine if the astonishing predictions of Einstein's theory are correct, including the freezing of time and the dragging of space around a black hole. The merger of two supermassive black holes, believed to occur during collisions between galaxies, is a catastrophic event in spacetime that also produces gravitational waves detectable throughout the entire Universe. These waves are gravitational "recordings" that document every massive black hole merger that has ever happened.

Constellation-X will greatly extend our capability for high-resolution x-ray spectroscopy. Its key goals are to use atoms falling into a black hole as probes of spacetime by tracking spectral features close to the black hole's event horizon, the theoretical black hole "surface." Constellation-X will also trace the evolution of black holes with cosmic time by obtaining detailed spectra of the most massive of these objects at the cores of galaxies throughout the Universe.

LISA will perhaps provide us with the first direct detection of gravitational radiation, a phenomenon predicted by Einstein's theory of gravity. It will detect supermassive black hole mergers that occur several times a year throughout the Universe, and will provide us with precise maps of the deformed structure of spacetime near the surface of a black hole, testing Einstein's theory.

A black hole finder probe will perform the first all-sky imaging census of accreting black holes—ones into which stars and gas are falling—ranging from supermassive black holes in the center of galaxies, to intermediate black holes produced by the very first stars, to stellar mass black holes in our own Galaxy.

Einstein's theory of space and time can be tested by experiments within the Solar System, such as high-precision ranging measurements. In addition, *Gravity Probe-B* is a polar-orbiting satellite that will measure two remarkable effects predicted by Einstein's General Theory of Relativity to unprecedented precision, both effects due to the distortion of spacetime created by the spinning mass of our Earth.

Objective 3: Understand the development of structure and the cycles of matter and energy in the evolving Universe.

The Universe is governed by cycles of matter and energy. Even as the Universe expands, pockets of atomic matter and dark matter collapse by the force of gravity to form galaxies and clusters of galaxies. Dense clouds of gas within galaxies collapse to form stars, in whose centers all of the elements heavier than hydrogen and helium are produced. When stars die, they eject some of these freshly produced, heavier elements into space, forming galactic clouds of gas and dust in which future generations of stars are born, beginning another cycle of matter.

The luminous energy from stars and from our Sun comes from thermonuclear fusion, in which hydrogen and helium gas are burned, leaving as "ash" the heavier elements. When a star's fuel is consumed, its life ends. For the most massive stars, the end comes as a supernova; the stellar core collapses to a neutron star or black hole, releasing vast quantities of gravitational energy that cause the supernova to momentarily outshine its host galaxy. This energy strongly affects the environment of nearby stars and is believed to be responsible for cosmic rays, atomic particles moving at near light constantly bombarding the Earth. Supernovae have also been associated with other extraordinary phenomena, such as gamma-ray bursts and cosmic jets.

The aim of the *Cycles of Matter and Energy* Program is to understand these cycles and how they created the conditions for our own existence. To understand how matter and energy are exchanged between stars and the interstellar medium, we must study winds, jets, and explosive events. To understand the formation of galaxies, we need to map the "invisible" Universe of dark matter that helped nucleate these structures, observe the gas expelled during the birth of galaxies, and witness the birth of the first black holes and their effect on the formation of galaxies.

The *Gamma-ray Large Area Space Telescope* (*GLAST*) will measure gamma rays emitted by a variety of extremely energetic objects, such as quasars. A quasar is a galaxy in which large quantities of gas are falling onto a supermassive black hole that occupies the galaxy center, releasing huge amounts of gravitational energy. This energy goes into the creation of cosmic jets, which shine as sharp beacons in the gamma ray region of the electromagnetic spectrum. By measuring the spectra of these emissions, this mission will explore the details of the complex interactions that occur in these "cosmic cauldrons."

An Explorer mission, *Swift*, will contribute to our understanding of the cycles of matter and energy. *Swift's* goal is to determine the origin of gamma-ray bursts, the most powerful explosions known to occur in the Universe. *Swift* will search for bursts in the gamma ray, X-ray, ultraviolet, and optical regions of the electromagnetic spectrum. *Swift* will rapidly point at gamma-ray bursts within seconds of their detection and simultaneously observe the burst with instruments in all of these wavelengths. It will also send a message to robotic telescopes on Earth to do the same.

Key Structure and Evolution of the Universe Technology Requirements

The *Beyond Einstein* program demands many improvements in technology. *Constellation-X* will need lightweight optics and cryogenic X-ray calorimeters. To keep *LISA's* test masses free of nongravitational forces, sensitive positional monitoring units coupled to micronewton thrusters are required. *LISA* will also need very stable laser measurement systems. These will enable LISA to detect the subtle remnants of gravitational radiation, which will alter the distances between spacecraft, separated by millions of kilometers by less than the *width of a proton*. The vision missions, a black hole imager and a Big Bang observer, need still greater precision in spacecraft pointing and control. The *Einstein Probes* require study of a broad range of technologies, such as large-array microwave bolometers and giga-pixel optical/infrared detectors, so that the most effective approach to their science goals can be chosen.

4.3 Technology Investments

As discussed in the Theme programs, each Theme has special, critical technology requirements. In addition, there are technology needs common to all space science endeavors. This section presents a summary of both the unique and the common, all of which are strategic investments in our ability to meet our Objectives.

As with our other programs, we use competitive selection through NRAs for nearly all technology efforts. We also collaborate with the other science Enterprises and the Aerospace Technology Enterprise to define requirements and leverage development activities.

The Space Science Enterprise prepares a Technology Implementation Strategy, updated in parallel with the Enterprise Strategy every three years. It includes the Space Science Enterprise Technology Blueprint, which is updated semiannually to reflect changes of requirements and technology advances.

The technology program pursues three key objectives. First, we strive to develop new and better technical approaches and capabilities in response to needs established for space-based scientific measurement systems. Where necessary, we then validate these capabilities in space so that they can be confidently applied to science flight projects. Finally, we apply these improved and demonstrated capabilities in the science programs and ultimately transfer them to U.S. industry for public use.

Acquiring new technical approaches and capabilities. When mission concepts are defined sufficiently to begin detailed scoping of their instrumentation, systems and infrastructure performance requirements are derived. Technology development is focused on satisfying these requirements (“mission pull” technologies).

Less-mature technology research (“vision pull”)—often pursued in close collaboration with the Aerospace Technology Enterprise (ATE)—is focused on more general measurement challenges. These are formulated, on the basis of priorities established by the National Academy of Sciences and by study groups who work with the science and technology communities. The challenges are designed to stimulate the breakthrough innovation that will enable new measurement approaches and mission concepts. Two recent initiatives (*In-Space Propulsion* and *Project Prometheus*) are particularly noteworthy examples of “vision pull” technologies derived from advanced studies. The balance between “mission pull” and “vision pull” aims to assure the adequacy and resiliency of the technology available to future science missions.

Validating new technologies in space. Technologies that are at a medium level of maturity are examined periodically to identify those promising candidates that could add significant value to future missions if demonstrated convincingly in an operational setting. These concepts are then selected competitively and are funded for space validation principally through the New Millennium Program and also through flight of opportunity missions. Ground validation of technologies not requiring space flight validation is accomplished through the focused technology programs of the space science Themes.

Applying and transferring technology. The technical requirements of the missions are often unique, due to the nature of the scientific undertaking. Nevertheless, by comparing requirements, we systematically seek the efficiency that derives from identifying common needs, and occasionally by aligning mission requirements that may be met by a coordinated technology development and application. This results in reduced mission costs and shortened development time across the programs.

The next generation of space science spacecraft will continue to be more capable and more reliable, but must also remain affordable. This requires new technologies to endow spacecraft with more on-board power for greater communication bandwidth, data analysis and autonomy. Propulsion capability must improve to reach deep space with more capable payloads, in less time, with the ability to carry out a wider range of scientific programs. New telescopes require much larger apertures for higher-resolution images and spectra. Constellation technology is needed to enable efficient, simultaneous data collection at dispersed locations. All of space science depends on continuing advances in sensors and detectors in the areas of sensitivity, accuracy and wavelength range. These advances, coupled with efficiencies in power and mass requirements, will lead to more cost-effect missions, both in the near-Earth environment and farther out into the Solar System. Many of these capabilities will also be invaluable for a future program of integrated human and robotic exploration.

During the preparation of the Enterprise Strategy, the Theme roadmap teams derived the key technical capabilities needed to implement their missions. The capabilities are synthesized into the Technology Blueprint—and summarized here—under three main headings: Remote Observing Technology, Technology for *In Situ* Exploration, and Space Systems Technology.

	Enterprise Themes				
	Solar System Exploration	Mars Exploration	Sun-Earth Connection	Astronomical Search for Origins	Structure and Evolution of the Universe
Remote Observing Technology					
Optics: lightweight mirrors and active optics			X	X	X
Remote sensors/detectors/instruments	X	X		X	X
Coolers			X	X	X
GNC*: constellation control, metrology			X	X	X
Technology for *In Situ* Exploration					
Robotics and planetary access	X	X			
Power for surface systems	X	X			
Entry, descent, and landing	X	X			
Ascent	X	X			
GNC*: rendezvous and sample capture	X	X			
Technology for extreme environments	X		X		
Planetary protection and sample handling	X	X			
In situ instrumentation	X	X	X		
Space Systems Technology					
Avionics	X		X		
Communications	X	X	X	X	X
GNC*: includes pointing, disturbance reduction	X		X	X	X
Information technology/Autonomy	X	X	X	X	X
Power	X	X	X		X
Propulsion	X	X	X		
Structures/materials	X		X	X	X
Thermal control and environmental effects	X	X	X	X	X

* GNC: Guidance, navigation and control

4.3.1 Remote Observing Technology

Future remote observing systems in space will require dramatically improved sensitivity, higher angular and temporal resolution, and broader spatial coverage. These requirements can be met by technology advances in four subsystem areas: space optics, advanced sensors and instruments, constellations of spacecraft, and advanced coolers. Advances in these subsystems in turn require advances in several technical disciplines: optics, controls, structures, materials, nanotechnology, coatings, information processing, microelectronics, thermal engineering, and systems analysis and modeling.

Several planned space telescopes require larger but much lighter and more precise primary mirrors than can now be achieved. This requires new **space optics** concepts coupled with advanced materials, structures, and controls. For example, some of the large primary mirrors will not fit within launch vehicles and need to be made and launched as segments to be deployed, reassembled, and aligned in space to simulate a continuous precision optical surface.

Sensor and instrument technology progress is needed to provide new observational capabilities for astrophysics, space physics, and solar and planetary science remote sensing, as well as vehicle health awareness. There are immediate needs for large-format array detectors and lightweight precision optics and coatings. Focal plane arrays that cover a larger area with a large number of pixels are needed to examine larger areas of the sky for both efficient operation and to measure the dynamics of complex phenomena. Large area, high efficiency, and high read-out speeds are needed for deep-sky surveys.

Advanced light sensors, particularly with higher response and lower noise in the far infrared and ultraviolet regions of the spectrum, are essential for observing systems of the next generation. **Spectroscopy** is required to discover extra-solar planets suitable for the support of life. Spectroscopy also enables scientists to understand the chemistry and physics of the gas and dust cloud surrounding a star in the planetary system formation stages of its evolution. New technology is needed to dramatically increase the efficiency of spectroscopic instruments used in conjunction with space observatories.

For some missions, **constellations of smaller spacecraft can accommodate the need for a single, large primary mirror, with a technique called interferometry, essentially a mixing of light waves, now done on Earth with radio and optical telescopes.** Each of the spacecraft in such constellations must be precisely controlled, however. Advanced wavefront metrology (a distance measuring technique) and active surface control (to tweak and focus mirrors) are also needed for segmented, sparse/synthetic, and interferometric aperture systems. Planet-finders employing interferometry will require coronagraphy and high-resolution imaging through active surface control and optical surfaces that are intrinsically ultraprecise and smooth.

One of the challenges in **constellation control** is to achieve precision positional and pointing accuracy for each element of the constellation. This requires very high-precision micro-thrusters and systems for sensing, metrology and control. Tiny satellites that can easily fit in one's hand carrying out *in situ* measurements will require less positional and pointing precision, but they may number in the tens or hundreds in a given constellation, requiring breakthroughs in the cost of **constellation operations**, most likely achievable through increased spacecraft and ground system autonomy.

Another key challenge for spacecraft clusters and constellations is to **reduce the unit cost of the craft** through the development of detectors, instruments, and integrated systems that are smaller, lighter, and more fault-tolerant and that use less power. Technologies developed to achieve these specific requirements for constellations will directly benefit all future missions, even those comprised of single spacecraft, through reduced cost and increased reliability.

Advances in long–life **cryocoolers** and **space-radiative coolers, which lower the temperature of the instrument environment to near absolute zero,** are needed to control the unwanted background radiation and noise at the focal plane of imaging instruments.

4.3.2 Technology for In Situ Exploration

Two categories of measurements fall under the classification "*in situ*": sampling of solids, gases, or fields on planetary or lunar surfaces and direct detection of fields and particles in space.

In coming decades, planetary exploration will change its focus from remote observation to *in situ* exploration and sample return missions. This means landing, digging samples, and bringing them back home. The key requirements for *in situ* planetary measurements are entry, descent and landing, robotics and planetary access, planetary protection, rendezvous and sample capture, and technology for extreme environments.

The most pressing need in "**entry-descent-landing" (EDL)** is safe, accurate autonomous landing on the surfaces of planets and small bodies. EDL techniques for small bodies and large bodies, and bodies with or without an atmosphere are significantly different.

Robotics and Planetary Access includes roaming the surface and digging underneath. Each planet or moon exploration requires a different technique. Increased autonomy is crucial for rovers to travel longer distances across Mars. Balloons and aircraft above Mars carry instruments that measure the atmosphere and regions on the surface not accessible from orbit or with a rover. Subsurface access, by means of drills, penetrators and impactors, is vital to the investigation of sedimentary climate records on Mars and for investigations of water and other volatiles on Mars and other planetary bodies. Titan and Venus require instruments that fly across these alien worlds.

Planetary Protection and Sample Handling are needed to avoid transporting Earth-organisms to planetary bodies that could contaminate the planet, appear in returned samples, or interfere with *in situ* instruments attempting to detect life. **Instruments** are needed to detect organisms at extremely low levels, along with robust cleaning methods for spacecraft. After samples are returned to Earth, they must be secured to prevent inadvertent release of potentially harmful material.

Autonomous Rendezvous and Sample Capture is needed for sample return missions, and requires the ability to locate, track, and capture autonomously a small sample canister in orbit or deep space for return to Earth.

Technologies for Extreme Environments is critical for *in situ* missions. Access to the surface of Venus and to depths in the Jupiter atmosphere, to conduct definitive measurements of bulk composition, requires instruments tolerating pressure of 100 bars (xx times sea-level air pressure) and temperatures approaching 500°C. They must also be resilient to extreme deceleration loads during planetary entry. For missions to the Jupiter system using nuclear propulsion, we will need radiation hardening to increase spacecraft tolerance to both the natural radiation of the Jupiter environment and the neutron radiation from the power source.

New technology makes possible **steady improvements in many types of *in situ* instrumentation**, including extending the range of particle detectors to higher and lower energies; achieving higher energy resolution at high energies; developing novel electric and magnetic field measurement techniques; and developing more effective techniques for measuring particle densities, compositions, and winds. In particular, more powerful digital electronics components make possible development of **enhanced burst memory and on-board processing** applied to all types of *in situ* measurements.

Similarly, future *in situ* **field and particle measurements** will require new technology development for the extreme environments they confront. One crucial requirement is the development of **heat shielding** with weight, size, and thermal isolation suitable to protect satellite systems and science instruments on a spacecraft deployed to within four solar radii of the Sun, or closer to the Sun than Mercury Another critical requirement is a **dust shield** to protect satellite systems and instruments from impacts of high-velocity particles in the inner solar system, some only the size of a speck but moving at xx% the speed of light. In addition, **hardened component**s for **selected instruments** must be developed for deployment on such a spacecraft to provide certain critically needed measurements that cannot be made from behind a heat shield.

4.3.3 Space Systems Technology

The space systems technology category serves all space science flight programs. It encompasses eight classic disciplines that make up a modern space system: Communications, Power, Propulsion, Avionics, Information and Autonomy, Guidance and Control, Thermal Control and Environmental Effects, and Structures and Materials.

Communications data transfer rates are a major limiting factor on science return from space missions, especially from spacecraft at planetary distances. Increased data rates are a critical need that may be met by emerging technology in X and Ka-bands, as well as optical communication. The Enterprise is leading a new initiative to develop optical communications capabilities (see box). Data compression tools and increased local communications capabilities are also needed.

Optical Communications

How frustrating it is to land on Mars, with the whole Earth watching, yet remain unable to efficiently communicate with and collect data from robotic rovers. Limitations in deep-space communication are a bottleneck to scientific discovery and public outreach. Yet the use of optical/laser communications technology will enable dramatic improvements in science data rates and will lower the cost per byte of data returned. The Optical Communications Initiative will demonstrate critical space and ground technologies in this decade and perform a flight demonstration in the next. The improvement is analogous to switching from an old 14.4-speed dial-up modem to Ethernet. The purpose is to demonstrate high-data-rate communication from Mars in the 2010 timeframe. Optical communications' potential must be demonstrated and quantified under operational scenarios.

The Optical Communications Initiative will develop technologies enabling return of much greater quantities of scientific data from long-duration science missions such as the Jupiter Icy Moons Orbiter. This new class of exploration missions, powered by nuclear fission, may include tours of multiple targets, extended orbital and surface stay times, and high-power science instruments—all of which lead to much larger quantities and higher rates of data return.

To make optical communications an operational program, we would need to complete the technology development of high-power lasers that will be capable of delivering vast quantities of scientific data from deep space missions. We would also need to develop the infrastructure of ground optical receivers to complement the Deep Space Network.

Power and propulsion technology requirements include higher efficiency power systems, advanced chemical and solar electric propulsion, micro-propulsion systems, solar sails, and aerocapture. Project Prometheus, which focuses on advanced radioisotope power generators and space-qualified nuclear reactors, is a major effort to meet these requirements. Project Prometheus will also develop advanced power conversion and propulsion subsystems that will be applicable across a broad range of missions.

Technology needs in **Avionics** include high-performance yet power-efficient and even ultra-low power processors, memory, sensor interfaces, data bus and architecture, packaging and interconnects.

Information and Autonomy technology typically involves shifting decision-making from the Earth to the spacecraft. There is also need for more on-board responsibility in housekeeping: monitoring, diagnosis and response. Key areas that are being addressed include autonomy, reliable software, modeling and simulation, improved onboard computational resources, science data analysis and knowledge discovery. While spacecraft designs are typically evolutionary, the pace of development in information technology is revolutionary, leading to a significant lag in infusion of state-of-the-art techniques into Space Science Enterprise missions. Steps have been undertaken to quicken the infusion process for new information technology.

Needs for **Guidance, Navigation and Control** (GNC) technology include sensors and actuators with unprecedented precision and the ability to reduce spacecraft disturbances, design trajectories, estimate flight path and metrology, and control attitude. Trajectory design technology is particularly needed for solar electric propulsion and solar sail missions. Flight path estimation is needed for *in situ* missions involving aerobots or landers.

Thermal Control requirements run the gamut from protection of spacecraft and instruments near the Sun or at Venus to cold environments at outer planets or near comets to spacecraft accommodation of cooled detectors and optics on observatories.

Structures and Materials requirements include light structures that retain strength, stability, and stiffness, balloon materials for harsh environments, membrane materials and booms for gossamer structures such as solar sails and large apertures, multifunction spacecraft structures, and simulation and test of material performance and durability in space.

4.4 *Management Practices, Principles, and Policies*

NASA has adopted a common set of implementing strategies to ensure the entire Agency is working safely and efficiently together. The Space Science Enterprise has incorporated these strategies in our management practices, as described in the Space Science Enterprise Management Handbook. The following table illustrates the Enterprise's implementation of these strategies.

NASA Implementing Strategy	Space Science Enterprise Implementation
IS-1 Achieve management and institutional excellence comparable to NASA's technical excellence	
Human Capital	Participate in strategic Human Capital initiatives. Support young researchers through competitive grants Collaborate on higher-education science materials
Competitive Sourcing	Mission and instrument Announcements of Opportunity (AOs) R&DA NASA Research Announcements (NRAs) Senior reviews for extended operations
Financial Management	Space Science Enterprise Management Handbook, which outlines financial management procedures.
Budget and Performance Integration	Theme structure Space Science Strategy IFMP implementation
IS-2 Demonstrate NASA leadership in the use of information technologies	NASA Virtual Observatory, Virtual Solar Observatory
IS-3 Enhance NASA's core engineering, management, and scientific capabilities and processes to ensure safety and mission success, increase performance, and reduce cost.	Implement 7120.5b through Space Science Enterprise Management Handbook, which incorporates requirements for systems engineering and reviews.
IS-4 Ensure that all NASA work environments, on Earth and in space, are safe, healthy, environmentally sound, and secure.	Space Science Enterprise Principles and Policies as articulated in 2003 Space Science Enterprise Strategy
IS-5 Manage risk and cost to endure success and provide the greatest value to the American public	Implement 7120.5b through Space Science Enterprise Management Handbook, which incorporates requirements for risk management

Our approach to accomplishing Enterprise Science Objectives is also founded on a set of fundamental principles that encompass the role of space science within NASA and govern the decision-making process.

Use scientific merit as the primary criterion for program planning and resource commitment.	To fulfill its obligation to the space science community and preserve science integrity, the Enterprise uses open competition and scientific peer review as the primary means for establishing merit for its flight programs. In planning, the first rule is to complete missions already started, except in the case of insurmountable technical or cost obstacles.
Base the Enterprise Strategy on Agency science objectives and structure its research and flight programs to implement these objectives.	Our processes call for development of strategies every three years. Science objectives are set in partnership with the scientific community, and mission formulation is based on these objectives within policy and budget constraints established by the Administrator, the President's Office of Management and Budget (OMB), and the Congress. The Enterprise defines missions via its strategic planning process and incorporates missions formulated by the scientific community through peer-reviewed competition.
Aggregate consecutive missions that address related science goals into "mission lines."	Mission lines are programs of related missions that share broad science goals. A stable funding profile for a series of related missions promotes continuity and flexibility in budget and technology planning. The first obligation is to meet flight-rate commitments for existing lines. Then the Enterprise structures flight programs according to science priorities to establish new lines.
Preserve safety as NASA's number one priority; this includes mission success and environmental safety, including the implementation of comprehensive controls on potential biological contamination from missions to or from other worlds.	Projects will not be approved for implementation until reserves appropriate to its level of technical risk and a clear technology path to successful implementation are demonstrated. Testing and reviews will be adequate to provide positive engineering assurance of sound implementation. Resource shortfalls will not be relieved by deviating from proven safety, engineering, and test practices.
Ensure the active participation of the research community outside NASA that is critical to success.	The outside community contributes vitally to strategic and programmatic planning, merit assurance via peer review, mission execution through participation in flight programs, and investigations supported by research grants programs. NASA science and technology programs conducted at the universities play an important role in maintaining the nation's academic research infrastructure and in supporting the development of the next generation of science and engineering professionals.
Ensure vigorous and timely interpretation of mission data, requiring that data acquired be made publicly available as soon as possible after scientific validation.	Other than in exceptional cases, data must be released within six months of acquisition and validation. In addition, Principal Investigators are required to publish their results in the peer-reviewed literature. All data are archived by NASA in publicly accessible data archives for the long-term use of the science community and the public.
Maintain essential	NASA Center staff provide enabling support to the

technical capabilities at the NASA Centers.	broader research community by serving as project scientists, maintaining "corporate memory", providing engineering support, and operating unique facilities. These staff scientists also compete with external researchers to fund their own research.
Apply new technology aggressively, within the constraints of prudent stewardship of public investment.	The relationship between science and technology continues to be bi-directional: scientific goals define directions for future technology investment and development, while emerging technology expands the frontier of possibilities for scientific investigation. To maintain the balance between risk and reward, new technologies are demonstrated, wherever possible, via validation in flight before incorporation into science missions.
Convey the results and excitement of our programs through formal education and public engagement.	To ensure infusion of fresh results from our programs into education and public engagement efforts, our policy is that each flight project must have an education and outreach component. The Enterprise has established a nationwide support infrastructure to coordinate the planning, development, and dissemination of educational material, and works closely with NASA's Education Enterprise.
Structure cooperation with international partners to maximize scientific return within the framework of Enterprise strategy priorities and sound risk-management principles.	Most of the Enterprise's flight programs have international components. In establishing these cooperative relationships, as indeed in all other aspects of our program, funding is allocated to U.S. participants in international programs through competitive peer review. Foreign participants in U.S. missions are likewise selected on the basis of merit.

Finally, international cooperation at NASA has been guided since the early 1960s by a uniform and unchanging set of principles. These principles, which have proven very successful over the years, have lent stability and predictability to our cooperative posture, essential for good planning.

NASA Principles for International Cooperation
Each participating government designates a central agency for the negotiation and supervision of joint efforts.
Agreements are forged on specific projects rather than generalized programs.
Each country accepts financial responsibility for its own contributions to joint projects.
The projects are of mutual scientific interest.
The cooperation provides for general publication of scientific results.

To these general Agency principles, the Space Science Enterprise adds a few additional management guidelines. Opportunities for foreign cooperation in U.S. missions, as well as contributions by U.S. investigators to foreign missions, are subject to the same requirements for open and competitive selection based on peer review for science quality. Data obtained from missions conducted cooperatively between NASA-supported investigators and foreign entities should observe the same policies for prompt availability of data as apply to purely domestic U.S. projects.

The Enterprise's resulting cooperative arrangements are nearly always bilateral, even on programs that have multiple participants. Their legal framework and the parties' roles and responsibilities are documented in formal written agreements negotiated by NASA's Office of External Relations under the oversight of the Department of State.

4.5 Partnerships

To accomplish its objectives, the Space Science Enterprise relies on contributions from a great diversity of partnerships. Closest to home, this includes relationships with other Enterprises that are governed by the "One NASA" principle. This represents a commitment to the shared Vision and Mission and integrated planning across Enterprises and NASA Centers.

From here, the circle of partnerships extends beyond NASA, to other government agencies with charters and capabilities different from NASA's but still essential to space science programs. Researchers in the university community have played a central role in NASA's space science program since the founding of NASA, and a large corps of external organizations have more recently become actively involved in the Enterprise's broad and vigorous education and public outreach program. In implementing its competitive sourcing mandate, NASA looks to industry to purchase goods and services of all kinds, so their availability from the private sector is essential for success.

The Space Science Enterprise's cooperative relationships with foreign space agencies deserve special mention. Provision for international partnerships was explicitly highlighted in the Space Act of 1958, NASA's founding charter, and the intervening four decades have seen a long series of fruitful joint scientific activities that have greatly enriched the U.S. space science programs.

Inside NASA

The Space Science Enterprise benefits from collaboration with and reliance on the other Agency Enterprises. In addition, the Enterprise depends on specialized supporting services from a variety of functional offices within the Agency. Key Enterprise relationships are with the Space Flight Enterprise, which provides launch services and vehicles, and the Aerospace Technology Enterprise, which manages a significant share of the Agency's fundamental technology programs, and the Earth Science Enterprise, with which we share scientific data.

Partnership with the NASA Centers is also vital to the implementation of the Space Science Enterprise's programs. The Jet Propulsion Laboratory and the Goddard Space Flight Center are the primary supporters of the Space Science Enterprise; however, nearly every other Center contributes to Space Science Objectives. The Centers are also responsible for carrying out and providing infrastructure for many of the Agency's implementing strategies, such as information technology initiatives.

Enterprises

Space Flight Enterprise. The Space Flight Enterprise is critical to the success of space science missions. It provides launch services and launch vehicles, access to and manifesting for International Space Station attach points, Shuttle manifesting for experiments and servicing missions, and crew/training for Hubble servicing.

The Space Flight Enterprise also manages the Tracking and Data Relay Satellite System (TDRSS) and the NASA Integrated Services Network.

The Space Science Enterprise also manages the Agency's Optical Communications development program that will improve all communication systems and the exploration of Mars. This exploration will be essential to enable any future human exploration undertaken jointly with the Office of Space Flight.

Aerospace Technology Enterprise. Together, the Space Science Enterprise and the Aerospace Technology Enterprise collaborate to develop technologies necessary to achieve long-term science goals. In most cases, the Aerospace Technology Enterprise invests in technology's earliest stages, guided by concept studies that indicate the priority investments that need to be undertaken. As the technology matures, it becomes the responsibility of the Space Science Enterprise to further advance it and apply to specific missions.

Earth Science Enterprise. The Space Science and Earth Science Enterprises share a number of resources, including the Deep Space Network, which is managed by the Office of Space Science. The Earth Science Enterprise provides all Agency science missions with ground network support.

Both the Earth and Space Science Enterprises support NASA's participation in the U.S. Global Change Research Program. Earth science missions support our Living With a Star (LWS) Program by providing data on total solar irradiance. In return, LWS provides space weather data inputs for global models of the Earth's atmosphere, including observations of irradiance, energetic particles, and ionospheric/mesospheric/thermospheric conditions.

Biological and Physical Research Enterprise. Along with the Earth Science Enterprise, the Biological and Physical Research Enterprise participates in formulating the Astrobiology Program and supports aspects of it. They also develop experiments that may help characterize the martian environment and its suitability for future human exploration.

The Space Science Enterprise also manages the development of optical communications technology. Both the Earth Science and Biological and Physical Research Enterprises may have applications and provide requirements for this new technology.

Education Enterprise

The Education Enterprise provides overall direction, guidance, and coordination of the NASA Education Program. The Space Science Enterprise's education and public outreach program is one component of this comprehensive Agency-wide education program.

Field Centers

Much essential focused technology is developed at the NASA Centers, and they are important repositories of Enterprise corporate memory and lessons-learned. The Jet Propulsion Laboratory and the Goddard Space Flight Center are Space Science's primary supporting Centers. The former is the Enterprise's chief source of technical and management support for Mars and Solar System exploration, the latter for astronomy, physics, and Sun-Earth Connection science. These two Centers are also the only two allocated the responsibility for program and project management of Space Science flight missions and, as such, interact with every program in Space Science. The Ames Research Center manages the Enterprise's Astrobiology Program. Other Centers are engaged in technology development, science activities, and evaluation of new and ongoing missions.

The Centers also provide vital support to the outside research community by providing expert knowledge and specialized test and development facilities. Center scientists and technologists also compete for funding for original investigations of their own. This has a dual advantage in that, in addition to advancing the state of our knowledge intrinsically, these "in-house" research efforts keep Center scientists' skills sharp and enhance their scientific currency.

The Centers are also important contributors to implementing the Space Science Enterprise's E/PO program.

External Partnerships

The Space Science Enterprise has established and maintains active relationships with a number of other federal agencies and programs, outside organizations, and international partners. In some of these relationships, NASA is a customer, in some a collaborator.

The Space Science Enterprise relies on external organizations for support in critical areas.

	NSF	DOE	DoD	DOC	State Dept.	Universities	Industry	E/PO Partners	International	NRC
Joint science funding	X								X	
Science instruments	X	X				X	X		X	
Science expertise	X					X			X	X
Research facilities, labs			X	X		X			X	
Technology	X	X				X	X			
Launch vehicles			X				X			
Antarctic facilities	X									
Radiation-hardened parts							X			
High-density power systems		X								
Nuclear materials		X								
Shared launch facilities			X							
Operational data (weather, etc.)			X	X						
Operational requirements			X	X						
Satellite tracking			X							
Int'l approval				X	X					
Peer review						X	X			X
Advisory committees						X				X
Education expertise	X					X		X		
Exhibition expertise	X							X		

National Science Foundation As the two primary federal agencies involved in the support of astronomy, solar physics, and other space sciences, NASA and the National Science Foundation (NSF) have a broad portfolio of past, current, and future collaborations. Currently, NASA and NSF jointly fund planet search programs, astrobiology science and technology investigations for exploring planets, long-term interdisciplinary studies of life in extreme environments, ground-based investigations in support of NASA missions, and technology development for the National Virtual Observatory.

The NSF is also responsible for supporting U.S. scientific activities in the Antarctic. In partnership with the Smithsonian Institution, NSF and NASA collaborate on the search for, collection, distribution, and curation of Antarctic meteorites. NASA and NSF have a joint program to use Antarctica as an analog for the space environment in developing long-range plans for Solar System exploration. Finally, NSF provides operational and logistical support for Antarctic ballooning campaigns, including NASA's long-duration balloon missions. None of these activities would be possible without the stewardship role that NSF performs for Antarctic-based research programs.

Department of Energy The Department of Energy is an essential partner to many NASA space science activities. The DOE has provided high-density nuclear power systems to NASA for more than 30 years. Radioisotope Thermoelectric Generators, built and provided to NASA by DOE, enabled a wide range of Solar System exploration missions—from Apollo and Viking to Voyager, as well as Galileo and Cassini-Huygens. DOE, in partnership with NASA, is developing the next generation of radioisotope power systems and space fission reactors. DOE also supports work on power conversion interfaces.

The DOE also develops instruments and sensors for NASA's space science missions, particularly through its national laboratories. Data from DOE missions also support the International Living With a Star Program and its predecessor, the International Solar Terrestrial Physics Program.

Department of Defense The Enterprise and the Department of Defense (DoD) rely on each other programmatically and scientifically. Shared launches, shared satellites, and joint use of facilities enable us to function more efficiently and effectively with limited resources. The agencies share interests in forecasting the sometimes-disruptive effects of space weather on communications, navigation, and radar and in understanding the constraints that variable conditions in space near Earth place on spacecraft design, reliability, and control. The DoD has an operational interest in space weather models and data. Both DoD and NASA participate in the multi-agency Community Coordinated Modeling Center (CCMC) that supports the transition of space weather data from research to operations.

NASA's Living With a Star Program relies on DoD to help set research priorities to address challenges that come from increased reliance on space and space-weather-sensitive systems. Space science researchers depend on data from DoD satellites, such as the Solar Mass Ejection Imager that has been launched on a Space Test Program mission, and from ground-based observing networks, such as the Improved Solar Observing Optical Network. Laboratories sponsored by the Office of Naval Research and the Air Force Office of Scientific Research provide invaluable scientific, technical, and engineering expertise for many NASA programs.

Department of Commerce (DOC) Since many research missions include important contributions from international co-investigators, Export Administration Regulations (EAR) administered by DOC affect foreign partnerships that are a key to many space science programs. Many NASA investigations depend on Department of Commerce (DOC) facilities, such as the National Institute of Standards and Technology (NIST) for standards for calibration of instruments.

The Sun-Earth Connection Division, particularly the Living With a Star (LWS) Program, partners with elements of the DOC, such as the National Oceanic and Atmospheric Administration's Space Environment Center for collection, analysis, and dissemination of data; it provides data models and analysis tools for use by the DOC; and relies on NOAA for solar remote sensing observations and *in situ* magnetospheric data. NASA currently has no plans to obtain routine, but crucial, *in situ* measurements of solar wind conditions at L1 after existing missions end; however, NASA stands ready to work with NOAA on this, as recommended in the NRC Solar and Space Physics decadal survey.

Department of State Since the Department of State has overall responsibility for managing U.S. relationships with other countries, NASA depends on the Department for guidance on official government policy toward other individual countries and the role of space cooperation in the U.S. relationship with them.

The State Department has statutory authority for approving negotiation and conclusion of all international agreements. As part of this responsibility, the State Department administers an inter-agency review process for international agreements. The Department is also responsible for administering the provisions of the International Traffic in Arms Regulations, including related exemptions and licenses. Because all "space systems" and most associated equipment and technologies are subject to these regulations, NASA and its investigator community and industrial contractors are closely tied to the Department of State for compliance with these regulations.

The Universities Universities play a crucial role in achieving the Space Science Enterprise Objectives. University investigators, who perform basic research and analyze data from space science missions, are often funded through the Research and Analysis programs. Also, university scientists are often Principal Investigators of space science flight missions. Scientific experts from universities populate space science advisory committees, working groups, and peer review committees, providing essential advice and input. Finally, through competitive grants, NASA supports students and young investigators as they acquire training through the Research and Analysis programs and develop into faculty members, instrument builders, and Principal Investigators of major flight missions.

Education and Public Outreach Cooperating Partners The NASA space science education and public outreach (E/PO) program complements the large investments in education being made by school districts, individual States, and other Federal agencies, particularly by the National Science Foundation and the Department of Education. We rely on partnerships with these organizations, as well as with education-oriented professional societies, education departments at colleges and universities, and major curriculum developers to leverage our space science content, technical expertise, and E/PO resources into efforts that have major national impact.

Other partners assist us in extending the reach of our education and public outreach efforts. Such partners include educational and scientific professional societies such as the National Science Teachers Association, special interest organizations such as the National Organization of Black Chemists and Chemical Engineers, and community organizations such as the Girl Scouts. Public broadcasting documentaries and other such projects designed to reach large audiences are also leveraged in similar ways.

Finally, our most essential partners are the universities, laboratories, NASA Centers, and industry contractors who carry out our space science missions and research programs. Because our education and public outreach efforts are embedded within their missions and programs, these partners have the primary responsibility for developing and implementing education and public outreach projects that capitalize on the unique mission science and technology.

Industry The aerospace industry also plays a critical role in the design, engineering, manufacture, construction, and testing of both large and small space missions; in the design, development, testing, and integration of advanced instruments; and in the development of advanced spacecraft, instrument, mission operations, and information system technologies. Many industry capabilities have been developed for commercial applications with DoD or NASA core technology support. The resulting extensive space industry infrastructure is available for use for space science purposes. While the Space Science Enterprise partners with industry in many areas, one of the most critical dependencies is for launch vehicles.

International Cooperation International cooperation brings several important advantages to Enterprise programs. First, it enables U.S. science to benefit from relevant expertise from around the world; this expertise includes not only synergistic capabilities in fundamental science, but in engineering knowledge and technology how-to as well. Further, foreign co-investment in our flight projects, and U.S. co-investment in theirs, can often significantly enhance the capability of a flight mission by adding instruments or other otherwise unavailable enhancements.

4.6 Resources

Human Resources

The Enterprise recognizes the national need for increasing the numbers of students who enter careers in science, technology, engineering, and mathematics in general, and space science in particular. To this end, the Space Science Enterprise's E/PO program is aimed at inspiring precollege students from a diverse range of backgrounds to consider careers in these areas. Through its research grants, the Enterprise supports graduate and post-doctoral students explicitly for the purpose of producing new generations of space scientists. As the Space Science Enterprise moves into new research fields, research funds are purposefully used to foster and facilitate the creation of new research communities. For example, conducting research in Astrobiology requires a focused effort to create a new research field and community. Project Prometheus will require the reinvigoration of nuclear engineering as a discipline in U.S. universities and a significant investment in U.S. universities as an integral element of the project.

The Space Science Enterprise also works with the Office of Human Resources to define specialized competencies needed in the future, such as nuclear engineering for Project Prometheus or gravitational physics for *the Laser Interferometer Space Antenna (LISA)* mission. The Office of Human Resources, in collaboration with Human Resources organizations at each Center, provides NASA with the strategic and tactical means to attract, recruit, retain and develop the human capital needed to successfully perform the Agency's functions. They continue to develop an integrated Workforce Planning and Analysis and Competency Management System to track the competencies the Agency needs and possesses among its civil service staff.

The Enterprise participates in and fully supports strategic initiatives and traditional programs--such as internships, intergovernmental personnel assignments, recruitment initiatives, and education programs--designed to ensure human capital requirements are met. The NASA Specialized Center for Research and Training programs at the Scripps Institution of Oceanography and the Rensselaer Polytechnic Institute, as well as the Astrobiology programs at Arizona State University, the University of Washington, and the University of Colorado, are recent examples of successful programs.

Capital Resources

Through allocation of resources for the full cost of each program, the Space Science Enterprise will ensure that those Centers executing its programs develop and sustain the facilities and infrastructure needed to carry out the goals and objectives of the Enterprise and the NASA vision.

Following the concepts and strategies of the NASA Facilities Engineering Functional Leadership Plan and the Agency's Real Property Strategic Plan, the Space Science Enterprise will work with the Facilities Engineering Division to develop programs and plans for the continual improvement of its ability to support its mission and programs.

For the Center managed by the Space Science Enterprise, the Jet Propulsion Laboratory, we will make certain requirements are incorporated into the Center Implementation Plan and supported by the Center Master Plan. The Deep Space Network (see box) is an example of a critical facility, used by the entire Agency, for which the Enterprise has stewardship.

The NASA Deep Space Network (DSN) is an international network of antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system, the universe and selected Earth-orbiting missions. The DSN currently consists of three deep-space communications facilities placed at longitudes approximately 120 degrees apart around the world: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. This strategic placement permits continuous observation of spacecraft as the Earth rotates, and helps to make the DSN the largest and most sensitive scientific telecommunications system in the world. The antennas and data delivery systems make it possible to acquire telemetry data from spacecraft, transmit commands to spacecraft, track spacecraft position and velocity, perform very-long-baseline interferometry observations, measure variations in radio waves for radio science experiments, gather science data, monitor and control the performance of the network. The instruments flown on spacecraft are now capable of taking more data than the DSN can capture. Increased aperture capacity and wider bandwidth are required to enable and optimize NASA science in the coming years.

Information Resources

The Chief Information Officer (CIO) is responsible for providing reliable, robust, and secure information technology infrastructure to support the mission of the agency. The Space Science Enterprise works with the Office of the Chief Information Officer to make maximum use of this capability and to ensure that our Enterprise-specific data, computing, and information services are consistent and fit within the overall architecture and standards established by the CIO. This includes close coordination with other Enterprises to consolidate requirements and share Agency-wide approaches wherever possible and appropriate to improve effectiveness and achieve efficiencies.

5 Relationship with Agency Performance Plan

As a federal agency, NASA must prepare a five-year strategic plan and update it every three years, as required by the Government and Performance and Results Act of 1993 (GPRA). Each of NASA's Enterprises develops its own strategic plan on the same schedule. Other requirements of the GPRA are that agencies also develop yearly performance plans and performance reports. An agency performance plan is aligned and delivered with the agency's budget and explains what progress the agency expects to make during the upcoming fiscal year against goals and objectives in its longer-term strategic plan with the requested appropriation. At the end of the fiscal year, the annual GPRA performance report compares agency performance during the year against the projections provided in that year's performance plan.

Document	Cycle (years)	Required by GPRA Statute?
Agency Strategic Plan	3	Yes
Enterprise Strategic Plans	3	No
Agency Performance Plan	1	Yes
Agency Performance Report	1	Yes

An Enterprise Strategy provides more detail about the Objectives and activities than the Agency-level plan. Thus, while not required by statute, the Enterprise plan is a supporting elaboration of the Agency strategic plan and is thereby integrated into the NASA GPRA performance management system. At the level of detail provided in NASA's Agency plan, it is difficult to assess and represent progress on an annual basis. Therefore, the Enterprise uses a more detailed breakdown of its Strategic Objectives into Research Focus Areas (RFAs) for this purpose. The RFAs (shown in **Appendix**) are also used to generate multi-year outcomes in the Performance Plan and in investigation solicitations to inform potential proposers of scientific areas of primary Enterprise interest.

5.1 Enterprise Strategic Planning

Beyond supporting the Agency in meeting its statutory obligation, the Space Science Enterprise Strategy has many other valuable functions.

Audience	Enterprise Plan Function
OMB and Congress	Program and budget advocacy
External Science Community	Documentation of consensus on goals and priorities
NASA Agency Requirements	Input to Agency strategic plan and other GPRA documents
The Public	Handbook on NASA Space Science goals and plans
NASA Enterprises	Information for inter-enterprise collaboration
NASA Space Science Enterprise	Convenient reference for programmatic decision-making

The Enterprise Strategy development process is dependent on the active involvement of outside parties, especially the space science research community. NRC's Space Studies Board and its discipline committees develop long-range strategic program assessments and recommendations. The SScAC, based on inputs from its own subcommittees, provides the Enterprise with roadmaps that integrate NRC and additional community inputs with technical, budget, and programmatic factors.

After the Enterprise assembles a draft strategy from these inputs, the draft is circulated to both the NRC and the SScAC for review and commentary. The result of this exhaustive process is a space science strategy that takes advantage of the best, specialized expertise available and represents a broad consensus of all parties engaged in promoting the nation's space science agenda.

6 External Factors

The Space Science Enterprise engages in scientific research for the benefit of the science community and the American public. We achieve our objectives against a changing backdrop of resources, results, technology support, national priorities, partnerships, market forces, and other variables. We persist in the pursuit of our objectives while remaining mindful of external factors beyond our control. These are some of those factors:

The Legislative and Policy Framework. The Agency's Mission and goals derive from legislation and Presidential policy. In 1958, Congress passed the National Aeronautics and Space Act, establishing NASA and directing it to carry out specific purposes. A succession of laws and national policies since then at times redirected, expanded, or refined NASA's role. Future changes in law and policy may invalidate or reinforce goals. Administration and congressional budget decisions also affect NASA's ability to meet the goals and objectives as set forth in this plan. The plan is consistent with the near-term budget estimates in NASA's FY 2004 budget request to Congress.

The Economy and Public Support. The strength of the economy and support of the public are also outside influences on NASA's ability to meet its goals and objectives. Our strategy is based upon the assumption that the economy will remain strong enough to support our budgets and our associated activities. We also assume continued public support. NASA's actions are critical in this equation. To win and keep public support, we must hold ourselves accountable for our performance, explain our activities, transfer technology whenever possible, and keep our goals and objectives in tune with the public.

Partnerships with Other Agencies and Nations. NASA conducts many projects with other organizations, agencies, and nations. NASA's international partnerships reflect the scope of each partner's aerospace capabilities and interests and our relations with each nation. We welcome new partnerships with other nations because they can enhance NASA's ability to achieve its goals and reduce its costs.

National Security/Homeland Security. From its earliest days, NASA has provided support to the DOD and other Federal and local agencies where there has been mutual interest in achieving a goal. For example, technologies developed for civil applications, such as remote-sensing capabilities and aviation safety improvements, also can be utilized to meet other civil and national security needs. The changing security environment can have a significant impact on national priorities and can affect what NASA does. The increasingly complex and dangerous world compels us to apply our expertise and technologies to improve homeland security.

Markets. Should space markets experience robust growth, NASA could benefit from the availability of low-cost services that also support space commerce. Alternatively, if launch markets continue to decline, NASA could experience higher launch costs because the launch industry would have a smaller business base over which to spread the fixed costs.

For example, NASA's space science missions are typically flown on small spacecraft and have been dependent on vehicles developed for Low Earth Orbit communications constellations. Because the market for small- to mid-sized launch vehicles cannot be sustained solely by the space science mission flight rate, the options for affordable access-to-space for small missions are dwindling. With the development of the Delta-IV and Atlas 5, the opportunities to fly multiple spacecraft on a single launch vehicle are increasing, but present considerable logistical hurdles.

Technology. Many of the Enterprise's objectives rely on future technological breakthroughs. The unpredictability of technological advances can either delay or accelerate the accomplishment of our goals. Also, our research and development efforts may yield unanticipated benefits that further other NASA goals and provide new technologies to assist industry and benefit the public.

Discovery. The space science objectives presented in this Strategy constitute a balanced program of what we believe to be valuable and feasible for the future. However, new discoveries may suddenly change them; discovery of unexpected phenomena could result in new objectives drawing resources away from other planned investigations. To cite perhaps the most extreme example, NASA is seeking evidence of life elsewhere in the universe. If we find it, NASA may have to radically reorient its goals.

7 Evaluation

The Enterprise's programs are diverse and range from fundamental research and technology development to flight mission development and operations. Determining the best allocation of resources is a major challenge and requires deeper and broader expertise than the NASA can provide internally. As a result, the Enterprise depends on a wide spectrum of independent science and program status assessments to inform its decision making. A majority of the participants in these reviews are drawn from the scientific community outside of NASA, but NASA personnel and technical consultants also play a role.

The evaluations span the range from merit evaluation of scientific proposals, through periodic assessments of science achievement and the status of the field, to strategic scientific and tactical programmatic recommendations.

Peer Review of Proposals

A bedrock principle for all of the Office of Space Science programs is that of peer review of the proposals submitted in response to open and broadly advertised research solicitations. Such reviews are carried out by panels of highly qualified scientists (for scientific issues), engineers (for technical issues), and managers (for financial and management issues), each of whom has been screened for their competence in their respective fields, as well as for freedom from conflicts of interest for the proposals that they are asked to examine. Typically every proposal is read in detail by several panel members and then discussed in open forum to arrive at a consensus opinion.

Although the details of the criteria vary depending on the nature of the solicitation, in general they can almost always be classified into one of three main categories:

- Scientific and/or technical merit including the competence of the proposer and the proposed plan of research;
- Relevance to NASA's Objectives as given in the solicitation; and
- Realism and reasonableness of the proposed cost and management plan.

Additional, subsidiary criteria may also be stated, for example, furthering NASA's objectives in education and public outreach, and the involvement of small and/or minority (including woman-owned) businesses.

The totality of these reviews are then combined using the stated priorities of these criteria to arrive at an overall figure of merit that is typically based on a five-point adjectival scale A NASA Selection Official makes the final selection from among the best proposals as allowed by the available budget and for program balance as may be necessary to achieve the program objectives.

Senior Reviews for Extended Operations

With only a few exceptions most space science satellites are able to continue operating in a productive manner well after their nominal "prime" missions have been achieved and, therefore, return valid science data either for the refinement of their original objectives or to accomplish an entirely new set of objectives For example, the International Sun-Earth Explorer satellite was sent to study a comet after completion of its primary mission of studying the solar wind input to Earth's magnetosphere. Although such extended operations are frequently fairly low cost compared to the prime mission, and typically only a few percent of the original cost of the mission itself, the amount of funds available to the Enterprise for Mission Operations and Data Analysis (MO&DA) is limited.

Therefore, in order to prioritize those missions that seek continued operation—perhaps as many as a half dozen or more—the Senior Review process was developed and is carried out every two years. A panel of distinguished, senior scientists who were not involved in the candidate missions are assembled to review in detail each mission that seeks support for continued operations and to recommend, in priority order, further MO&DA funding over the course of the next three years. This process has been carried out for the last decade and has proven to be a fair process that is accepted by the science communities for determining which missions should be terminated. In a few such cases, these missions have been turned over to non-NASA institutions, typically a university, to operate for training its students.

Committees Chartered under the Federal Advisory Committee Act (FACA)

NASA's senior FACA-chartered advisory body, the NASA Advisory Council, advises the Administrator. The Council has a number of subordinate committees that serve an analogous purpose for the Enterprises; the Space Science Enterprise's advisory body, which reports to the Associate Administrator for Space Science, is the Space Science Advisory Committee (SScAC). The SScAC provides scientific, technical, and programmatic advice to the Enterprise on behalf of the broader outside research community. The Committee also serves to transmit information about policies and decisions of the Enterprise to its constituent research community members. The SScAC typically meets three times per year, as do each of four Theme science subcommittees.

In addition, the SScAC has a major role in assessing the Enterprise's scientific performance as part of the Agency's annual GPRA performance report. Once a year the Enterprise prepares a self-assessment of the status of the space science program in terms of the Strategic Objectives and Research Focus Areas. The SScAC receives its subcommittees' response to this self-assessment and delivers an independent assessment for incorporation into the Agency's annual performance report.

The chair of the SScAC Committee sits, *ex officio*, on the NASA Advisory Council, providing a conduit for the Committee's views to be offered as independent advice at the Administrator's level.

Finally, the National Astronomy and Astrophysics Advisory Committee (NAAAC) is chartered by Congress to provide advice to NASA on the coordination of its astronomy program with that of the National Science Foundation.

National Research Council

In addition to the input received from the SScAC, the Space Science Enterprise also solicits and receives independent advice from boards and committees of the National Research Council (NRC). Unlike the SScAC, the NRC appoints its own members and sets its own meeting agendas; the Agency's only control over studies performed by the NRC is to set their terms of reference and negotiate a schedule and cost for the studies. Particularly valuable reports developed by the NRC are the "decadal surveys" carried out in the various fields of space science. These surveys engage large parts of their constituent scientific communities to assess the state of knowledge in their fields and prepare recommendations for the next ten years. These surveys at once provide clear guidance for Agency decision making and also serve to build consensus within the highly diverse fields.

The Space Studies Board and its science discipline committees are the Enterprise's principal independent source of strategic science advice. The Board and each of its six or so standing discipline committees meet three times or so times per year to work on assigned Enterprise advisory tasks.

Management Reviews

The NASA Strategic Management Handbook establishes that the Agency's programs are to be overseen by a hierarchy of Program Management Councils (PMC). The Agency PMC at NASA Headquarters is responsible for evaluating proposals for new programs, for providing approval recommendations to the Administrator, and for assessing programs of high visibility or cost to ensure that NASA is meeting its commitments. Other PMCs are established at the Enterprise level (EPMC), at the assigned project Center, at supporting NASA Centers, and at lower levels within each Center as required. Similar to the Agency PMC, these councils evaluate project cost, schedule, and technical content to ensure that NASA is meeting the commitments specified in the Program Commitment Agreement, the Program Plan, and the Project Plan.

The "governing" Program Management Council for a specific project is the highest level PMC that regularly reviews that given project. EPMC meetings are convened whenever major programmatic decisions are needed, such as for confirmation of a project to transition from Formulation to Implementation, or for termination reviews. In addition, monthly flight program reviews are held to assess program and project progress and performance against the program-level requirements, the cost plan, and the development schedule.

Various independent performance assessments are conducted by external teams throughout the life cycle and reported to the governing PMC.